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THE DESIGN OF THE FLEXI-GROW HOUSING SYSTEM

BY

© JOON-DALL CHOE

A THESIS

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The undersigned certify that they have read and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "THE DESIGN OF THE FLEXI-GROW HOUSING SYSTEM" submitted by JOON-DALL CHOE in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

This thesis was undertaken to design the FLEXI-GROW housing system. This system represents a housing concept that is marketable and appealing to the tenant with major emphasis being placed on flexibility.

The results of the study indicate that the function of the FLEXI-GROW housing system can be accomplished by adopting prefabricated panels, suitable connecting and locking mechanisms and the chosen load bearing structure.

Recommendations are made where it is felt that further research on a possible mass production system would be useful.

ACKNOWLEDGEMENTS

The author would like to express his appreciation to Dr. J.C. Sprague for his guidance and supervision. Thanks are due also to Miss H. Wozniuk for typing this thesis.

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CHAPTER I

INTRODUCTION

Canada is young and an expanding country which has experienced exceptional population growth to date. One of our national objectives is to develop programs for the improvement of housing throughout the land. Canada must build 2,500,000 new dwellings in the coming decade to match our housing needs. Today, more than 14,000,000 Canadians are city-dwellers, and this number will likely more than double by the end of the century [9].

The housing construction industry and the government have continuously sought new innovations to supply this increasing demand. The rising cost of residential dwellings in this country has reached the point where the cost of a residential dwelling is out of reach of the average income family. Because of this rising cost and a housing shortage, there is a great need of new ways and means for the construction of dwellings that are within reach of the average income family. Traditional patterns continue to shape the production of housing with a limited number of prefabricated homes. What is needed is new planning, new programming, a new approach to design, and the application of modern production techniques to home building.

This study has been aimed at designing a housing system which will solve the housing problem for mainly low to medium income families. It has been proposed that houses be constructed with enough flexibility to expand and change with the families needs.

It is called the FLEXI-GROW housing system. This system allows the family to start with a small house and expand it economically as desired. The home has been designed to meet the changing demands of the tenant and to keep the initial investment to a minimum.

The FLEXI-GROW housing system provides prefabricated panels which are manufactured in the factory and assembled on the site. All major housing components, for example, wall sections, roof sections and floor sections are provided by panels. The load bearing structures are provided separately from the wall panels, therefore, every exterior wall panel or interior wall panel is free to be relocated. In order for interior and exterior walls to offer this flexibility a suitable connecting and locking mechanism for these walls has been developed. Every component of the FLEXI-GROW housing system was designed with factory production as its basis and with major emphasis being placed on erection simplicity and flexibility.

The erection of a home using this panel system can easily be taught to people inexperienced with on the site building. Panels can be prefinished including windows, doors and water proofing. Shipment, handling and assembly are easily accomplished with trouble free tolerances and ruggedness. The panels can be readily handled without complicated equipment.

Several floor plans are offered within the basic home module of 960 square feet. This basic floor plan can readily be rearranged and extended as the desire arises at a minimum cost and within a minimum of time.

1.1 Methodology Applied to the Study

Any system to be studied can be approached with one of several methods or strategies. The methodology applied to this system is basically as outlined by Nadler [15] as the Ideals (Ideal Design of Effective and Logical Systems) Concept. The basic concept is to design an ideal workable system for conditions of regularity to serve as a guide for developing the recommended work system. This system will be compatible with the actual restrictions which are given. The present system is not used directly as a guide for developing the recommended system. Therefore, the recommended system will stay as close as possible to the ideal workable system.

The steps involved in the design strategy for setting up such a system can be stated as follows:

1. Be aware of the system,
2. Define the problem,
3. Develop the ideal system,
4. Locate, evaluate, and organize the relevant information,
5. Select a solution,
6. Evaluate the Solution,
7. Apply the solution, and
8. Control the system.

CHAPTER II

THE FLEXI-GROW HOUSING SYSTEM

2.1 Problem Statement

During 1971, in Canada, the net increase in family formation was estimated to be 110,000. Net family formation is comprised of marriages and net immigration of families in terms of additions, and deaths of married persons and divorces in terms of losses. There were 195,000 marriages during 1971, a steady increase attributed to the echo effect of the post-war baby boom. Immigration added 20,000 to the family formation total [9]. The majority of net family formations are through marriages.

Average ages of brides and bridegrooms for first marriages are 22 and 25, respectively [12]. The average age of the NHA borrower is 33 years, and the borrower has, on the average, two children (see Figure 2.1 and 2.2). The proportion of borrowers who had not previously owned homes was 75.3 percent for 1971 and is increasing each year (see Figure 2.3). These statistics indicate that most young couples rent housing during the first eight years of their marriage.

Young couples should be able to move into their own home when they get married. Unfortunately most young couples cannot afford to buy the conventional type home that is available on the market today.

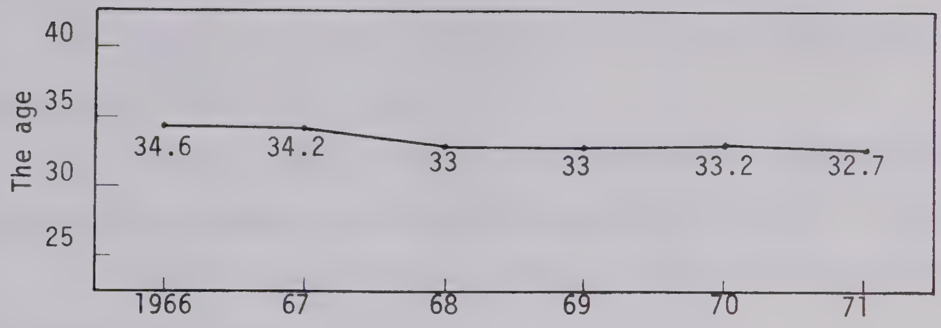


Figure 2.1 The average age of the NHA borrower [9]

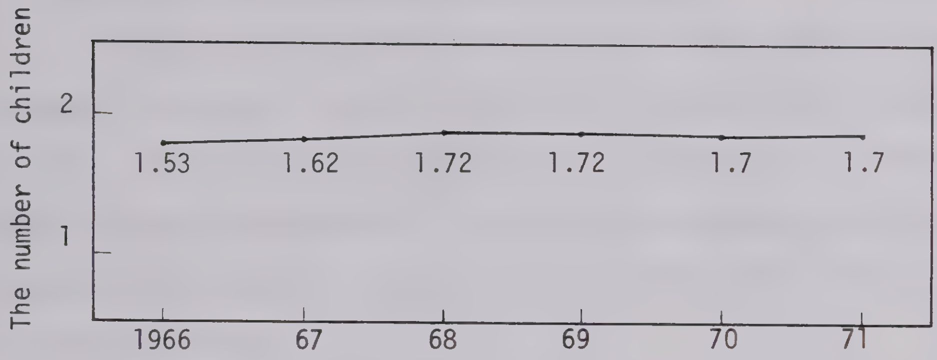


Figure 2.2 The average number of children of the NHA borrower [9]

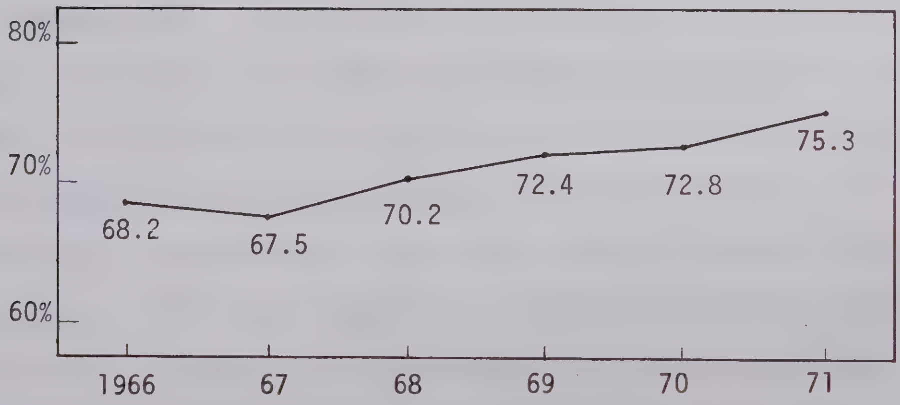


Figure 2.3 The proportion of borrowers who had not previously owned their own homes [9]

There is a strong need for a housing system that is:

1. Appealing to and functional for all tenants, especially during early years of marriage.

2. Flexible enough in construction that major changes can be made to interiors and exteriors in accordance with a tenant's needs.

3. Available to all income levels, and more specifically to the low income levels.

2.2 The Function of the FLEXI-GROW Housing System

The system chosen for detailed design will accomplish the function: "to develop a housing system that is appealing, economically feasible, and functional to families in all income levels". The chosen system will be referred to as the FLEXI-GROW housing system. The prime consideration of this system is complete flexibility at all levels of design.

The interior of the dwelling will allow complete flexibility of the enclosed area to change the floor plan as the tenant desires at a minimum cost. The outer walls of the dwelling will be so designed that expansion is possible to accommodate the desires of the tenant. A young family should be able to purchase a home that meets their budget and their requirements as their needs dictate. Restructure of the inner floor plan within the existing walls and/or restructure of the total floor plan including an expansion of the outer walls is possible at a cost that will be appealing to most tenants.

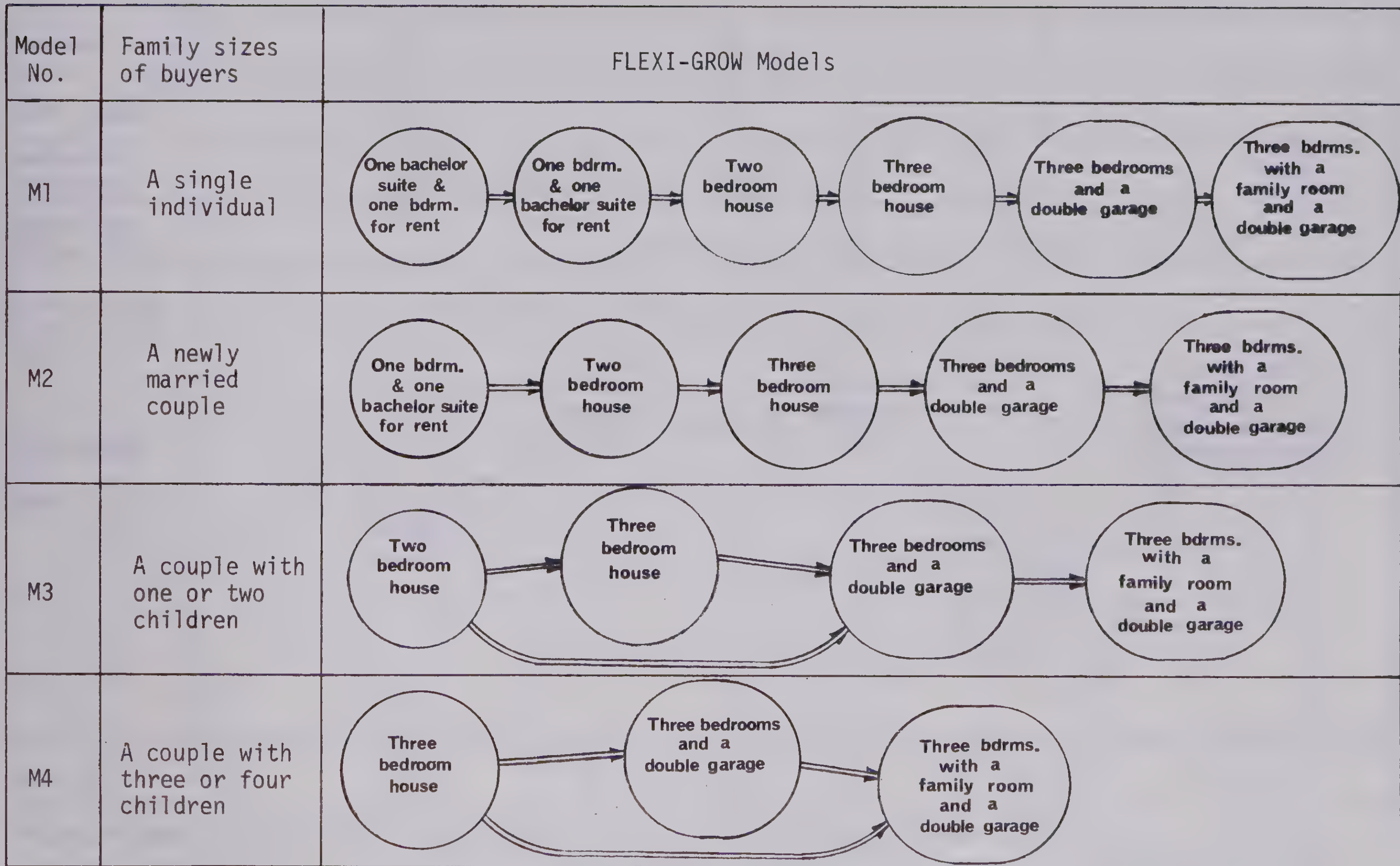
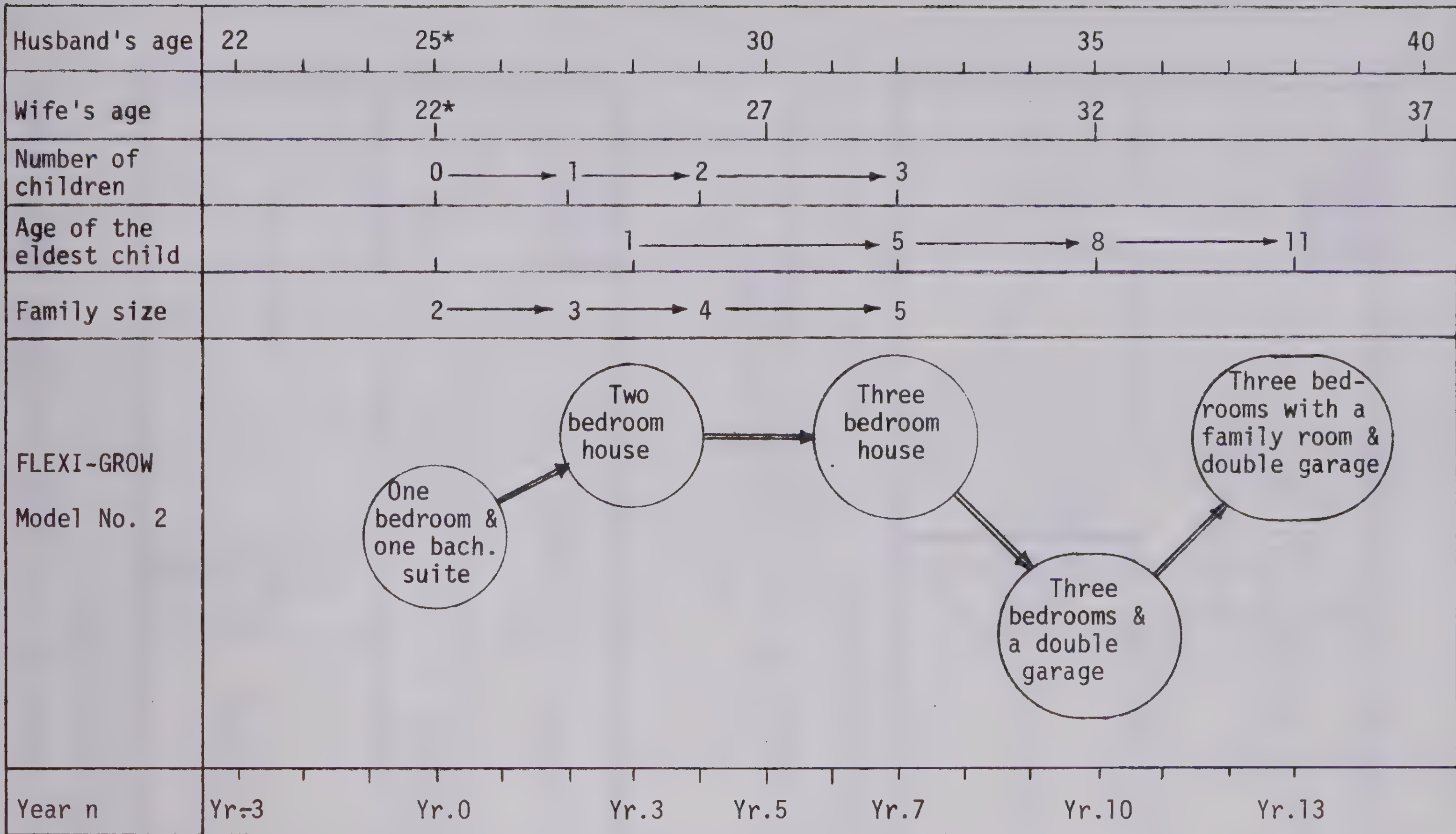
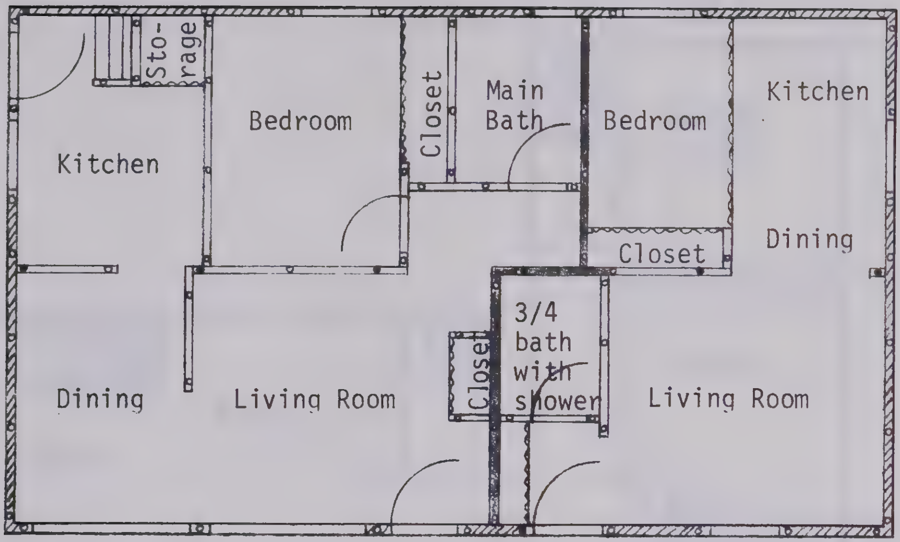


Figure 2.4 Several possible models of the FLEXI-GROW housing system



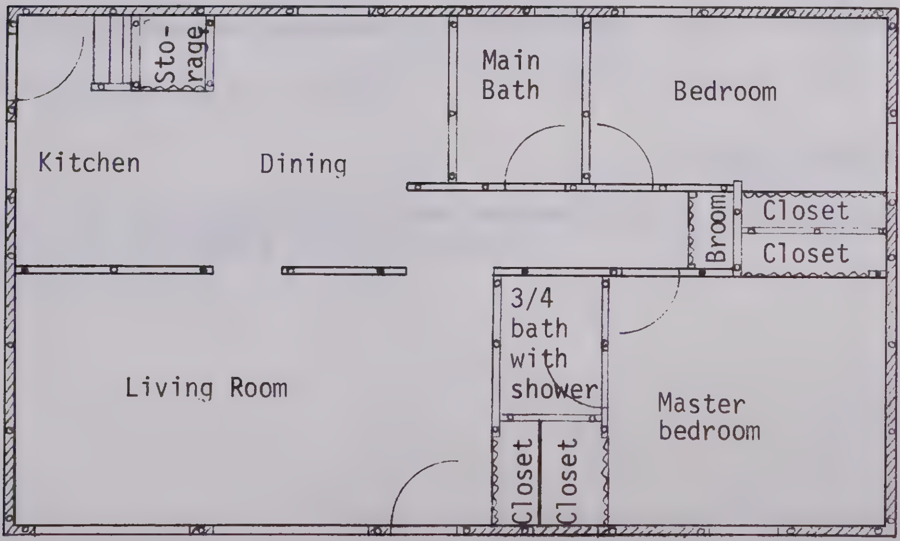
*Average ages of brides and bridegrooms for their first marriages in 1968 [12]

Figure 2.5 The FLEXI-GROW Model No. 2 housing system



Scale: 1/96(1/8" = 1')

Figure 2.6 960 square feet (40' x 24') One bedroom floor plan (576 square feet) with one bachelor suite (384 square feet)



Scale: 1/96(1/8" = 1')

Figure 2.7 960 square feet (40' x 24') Two bedroom floor plan

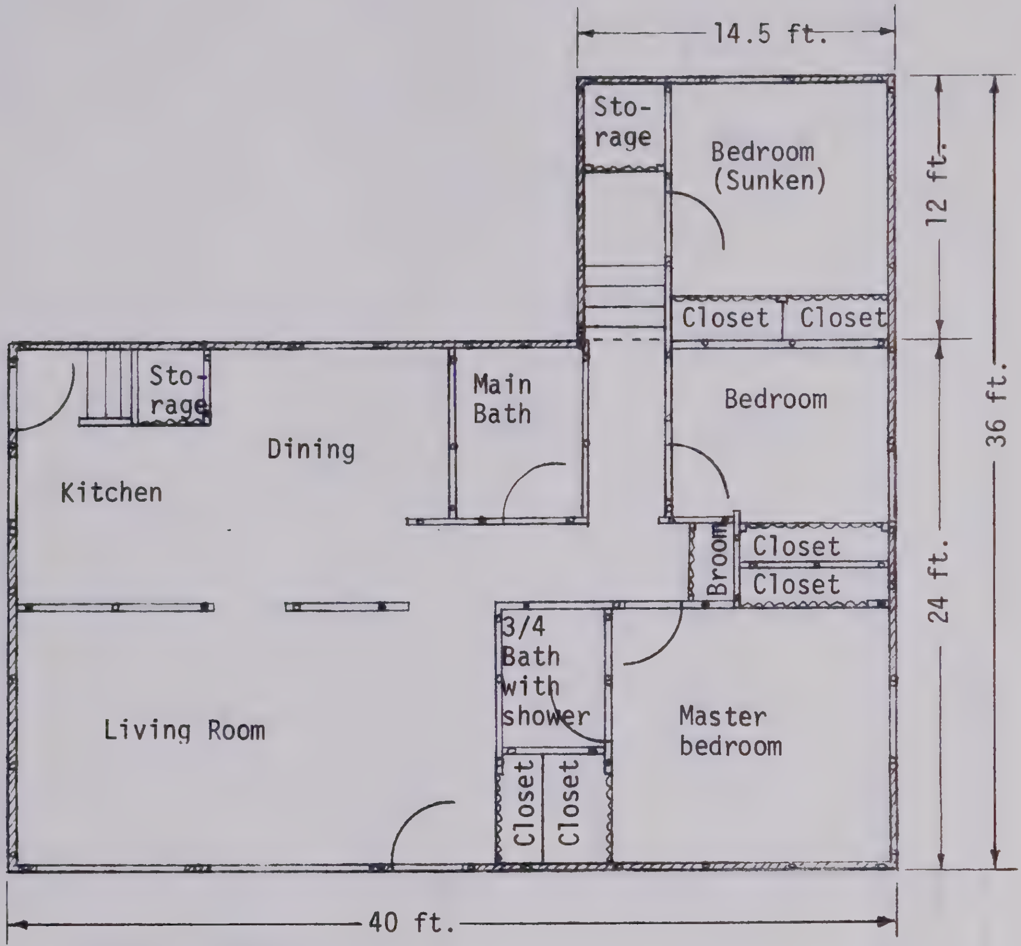


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Figure 2.8 1134 square feet Three bedroom floor plan including 174 square feet extension

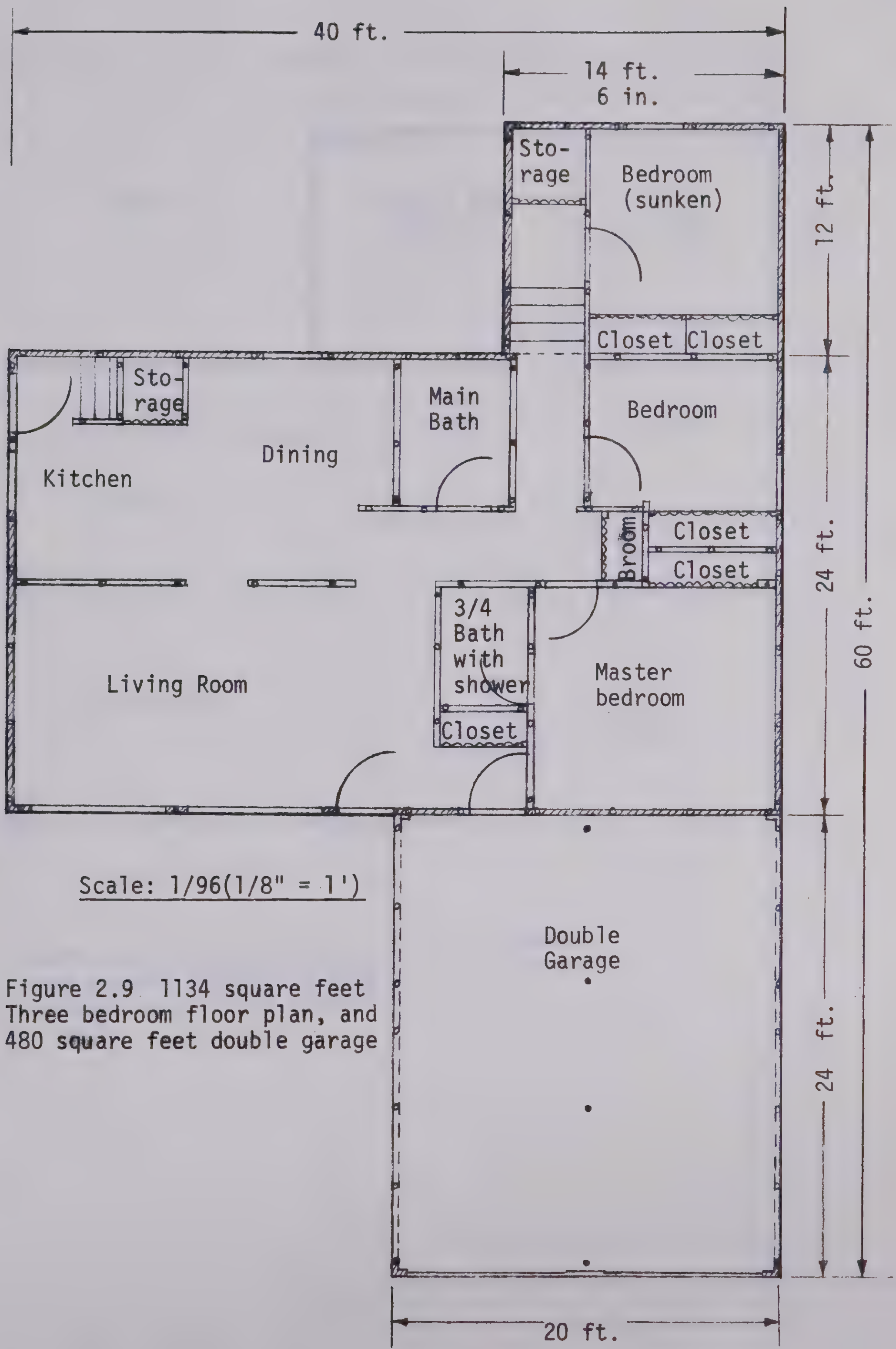
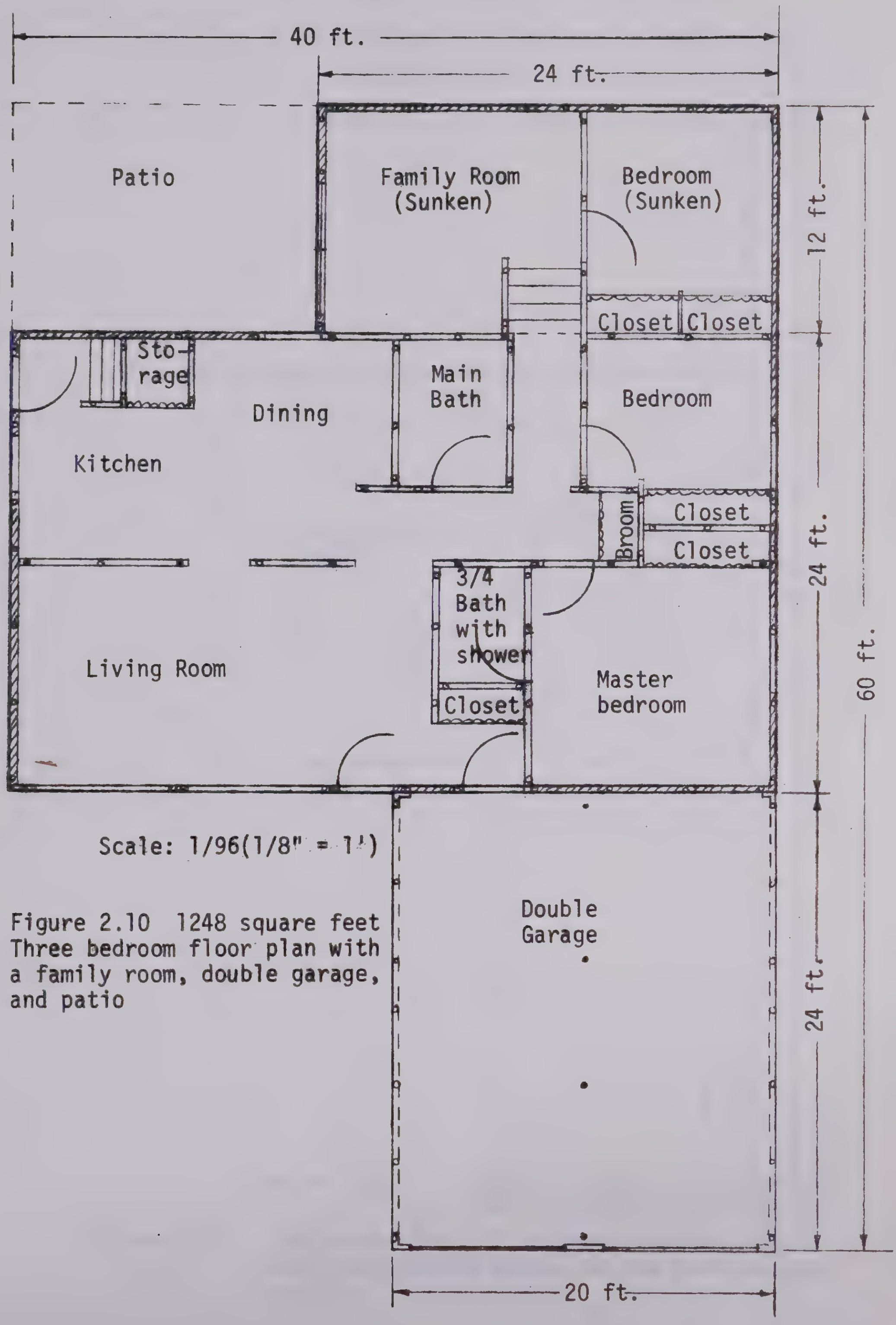


Figure 2.9 1134 square feet
Three bedroom floor plan, and
480 square feet double garage



Scale: 1/96(1/8" = 1')

Figure 2.10 1248 square feet
Three bedroom floor plan with
a family room, double garage,
and patio

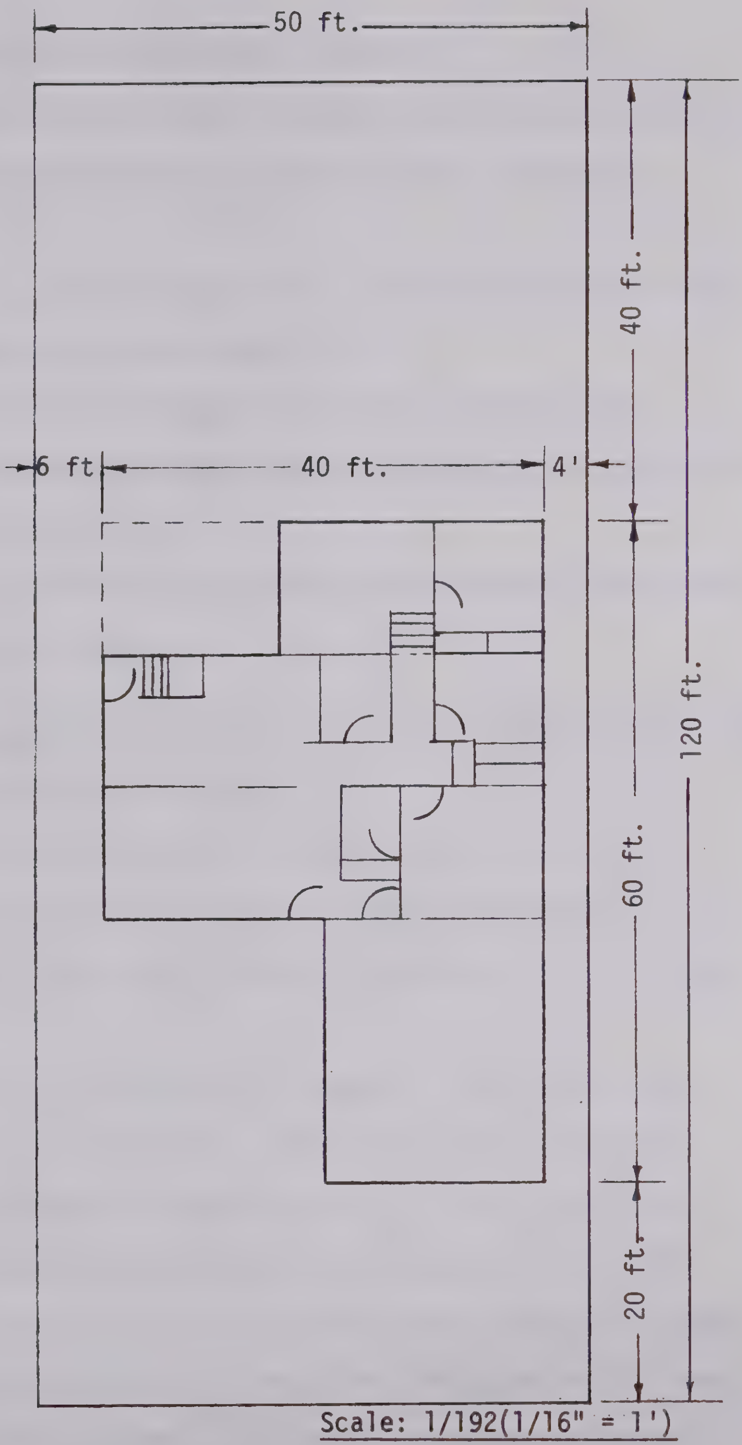


Figure 2.11 1248 square feet Three bedroom floor plan, patio, and double garage on the 6,000 square foot lot

2.3 Models of the FLEXI-GROW Housing System

Possible models of the FLEXI-GROW housing system are classified to satisfy the requirements or desires of the family (see Figure 2.4).

Model No. 1 should appeal to a single individual who would like to own a home prior to marriage.

Model No. 2 should appeal to a newly married couple.

Model No. 3 is designed to meet the needs of a family which has one or two children.

Model No. 4 is designed to meet the needs of a family which has three or four children.

2.4 Economic Feasibility Study of a Typical FLEXI-GROW Housing System

2.4.1 The Chosen Model for the Study

The model chosen for the economic feasibility study is model No. 2 which should be appealing to young couples who want to have their own dwelling units as soon as they are married (see Figure 2.5).

The basic floor plan of this model is 960 square feet (40 ft. x 24 ft) (see Figure 2.6). This house has two separate entrances and represents two dwelling units, a one bedroom suite containing 576 square feet of comfortable living space with 960 square feet of basement area for the couples who purchase this home and a one bedroom bachelor suite containing 384 square feet of comfortable living space for rent. The prime accommodation includes a kitchen, dining room, living room, bathroom and one bedroom. The suite for rent includes one bedroom in combination with a kitchen and

dining area, living room and a three-quarter bath. The estimated cost of this house including land and a full basement is $19,720 (see Table 2.2).

When desired a two bedroom floor plan may be arranged by the FLEXI-GROW No. 1 system which restructures the floor plan within the existing exterior walls. The estimated cost of this change, should it occur in 1974, is $500 (see Table 2.2 and Appendix A). The rearranged two bedroom house has two bedrooms, living room, kitchen, dining room, main bath and a three-quarter bath off the master bedroom (see Figure 2.7). This floor plan should be very functional for a young family with two children.

When required, a three bedroom floor plan may be arranged by the FLEXI-GROW No. 2 system which may add one more bedroom to meet the change in family size (see Figure 2.8). The extension of 174 square feet for one bedroom will make the total functional floor area 1134 square feet. The estimated cost of the 174 square feet extension (FLEXI-GROW No. 2) is $3,436 if made in year seven, 1978 (see Table 2.2).

When finances permit the family may wish to add a double garage referred to as the FLEXI-GROW No. 3 system (see Figure 2.9). The estimated cost of a 20 feet x 24 feet double garage, should it occur in 1981, is $1,815 (see Table 2.2).

A further addition of a family room and a patio may be considered to meet the families needs. The extension of 114 square feet for a family room will make the total floor area 1248 square feet

(see Figure 2.10). The estimated cost of the 114 square feet extension and the 192 square feet cemented patio area is $2,857. if made in year 13, 1984 (see Table 2.2).

Consequently, the final floor plan would be a 1248 square feet three bedroom home with a family room, a double garage, and a patio on a 6,000 square feet lot (see Figure 2.11).

2.4.2 The Estimated Cost of the Chosen Model

The average cost of new housing is increasing every year. The average construction cost per square foot has increased by 4-7% per year over the past six years (see Figure 2.12). Land cost has increased more rapidly than construction cost, for example, by 14.7% during 1971 (see Figure 2.13). Land costs vary according to the location of the land. To estimate the land cost of the chosen model, the average land cost for NHA* bungalows during 1971 (close to $4,900.) was used as a base.

The estimated construction cost per square foot, land cost, and double garage, cost for any given year (n), as presented in Table 2.1, were calculated by using the least squares forecasting method. This method of forecasting is outlined in Appendix B.

The estimated cost of the chosen model is presented in Table 2.2.

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*National Housing Act

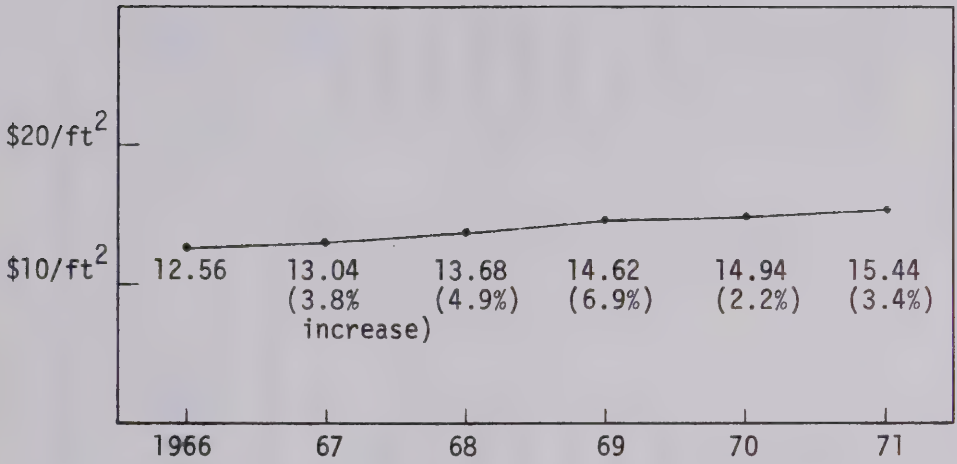

Figure 2.12 The average construction cost per square foot [9]

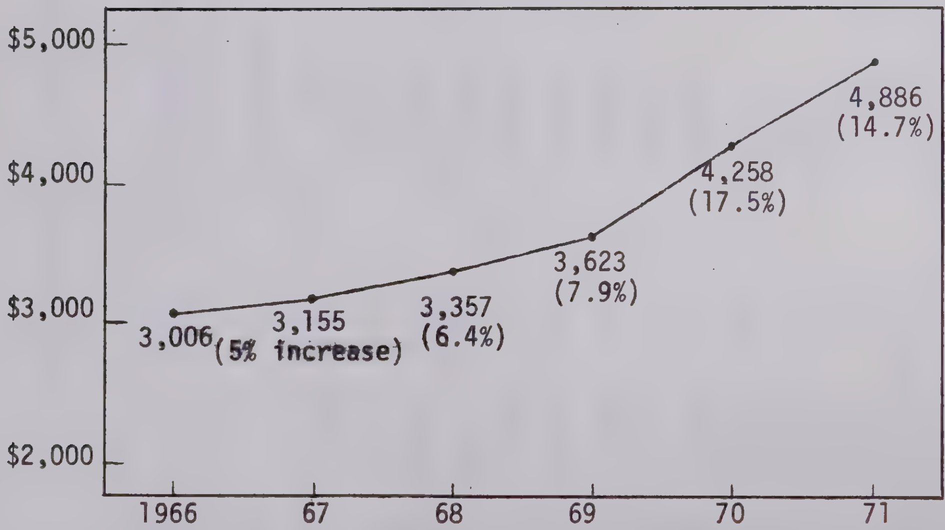

Figure 2.13 The average land cost for NHA bungalows [9]

Table 2.1

Forecasting Cost of Construction, Land, and Garage (see Appendix B)

Year Code	Year	Year No.	Average construction cost ($/ft^2)	Average Land Cost ($/lot)	Double Garage (20'x24') ($)
n		X	$\hat{Y}_c=11.94+0.601X$	$\hat{Y}_L=(2.425+0.37X)x1,000$	$1300 \times \frac{\hat{Y}_c \text{ at Yr.X}}{15.44}$
1	1972	7	16.15	5,015	1,359.67
2	1973	8	16.75	5,385	1,410.24
3	1974	9	17.35	5,755	1,460.81
4	1975	10	17.95	6,125	1,511.25
5	1976	11	18.55	6,495	1,561.82
6	1977	12	19.15	6,865	1,612.26
7	1978	13	19.75	7,235	1,662.83
8	1979	14	20.35	7,605	1,713.40
9	1980	15	20.96	7,975	1,764.75
10	1981	16	21.56	8,345	1,815.19
11	1982	17	22.16	8,715	1,865.76
12	1983	18	22.76	9,085	1,916.20
13	1984	19	23.36	9,455	1,966.77
25	1996	31		13,895	

Table 2.2

The Estimated Costs of the Chosen Model

Year No.		3	7	10	13
	1971	1974	1978	1981	1984
	One bedroom and one bachelor suite for rent	Two bedroom house	Three bedroom house	Three bedrooms and a double garage	Three bedrooms with a family room and a double garage
Land	\$4,900*				
Building	$960ft^2$x\$15.44/ft^2* = \$14,820				
Change of Floor Plan		\$500			
Extension of Floor Plan			$174ft^2$x\$19.75/ft^2** = \$3,436	20'x24'double garage \$1,815**	$114ft^2$x\$23.36/ft^2** = \$2,663, and \$194***
Total Floor Area	$960ft^2$	$960ft^2$	$1134ft^2$	$1134ft^2$ and double garage	$1248ft^2$,Patio (192 ft^2), and double garage
Total Cost	\$19,720	\$500(F_1****)	\$3,436(F_2****)	\$1,815 (F_3****)	\$2,857(F_4****)

*1971 Average cost for NHA bungalows

**See table 2.1

***Cemented patio area; 192 ft^2 x \$6/yd^2 x 1 yd^2/9 ft^2 x 23.36/15.44 = \$194

****F_i(i=1,2,3,4); FLEXI-GROW No. 1, No. 2, No. 3, and No. 4

2.4.3 Payment Schedule for the Chosen Model

As shown in the previous section any desired FLEXI-GROW housing model spreads the total investment over several years. This should be a definite advantage to the purchaser.

When purchasing a new house the family should give careful consideration to the down payment versus the monthly payments. The amount of the down payment and monthly payments may be varied within limits, in accordance with the buyer's financial situation and the mortgage period. The down payment represents a first burden to the buyer, and the amount of the down payment has a strong influence on the size of the monthly payments.

For young families and/or low income families both a low down payment and relatively low monthly payments in the initial years are usually essential when purchasing a home.

The FLEXI-GROW housing system accomplishes both of these major considerations to a greater degree than any housing system on the market today.

Cash Flow Calculations

To portray the effectiveness of the FLEXI-GROW housing system in accomplishing a desirable payment schedule, the model number two, outlined in Table 2.2 is once again used.

Assumptions:

(1)	Basic floor plan	= 960 square feet on a 6,000 square foot lot
(2)	First cost of the home	= \$19,720 in year 0, 1971
(3)	Down payment	= \$2,000 in year 0, 1971

(4)	FLEXI-GROW No. 1	= \$500 in year 3, 1974
(5)	FLEXI-GROW No. 2	= \$3,436 in year 7, 1978
(6)	FLEXI-GROW No. 3	= \$1,815 in year 10, 1981
(7)	FLEXI-GROW No. 4	= \$2,857 in year 13, 1984
(8)	Mortgage Life	= 25 years
(9)	Interest rate of mortgage	= 10% per year (0.833%/month)
(10)	Net interest rate after taxes of a bond or savings	= 6% per year (0.5%/month)
(11)	Property taxes	= \$480 per year (\$40/month)
(12)	Income taxes	= based on 1971 individual income tax regulations

(13) The bachelor suite is assumed to be rented for \$110/month for the first three years except for the very first month. (Monthly rental income after tax = \$78.70)

Symbols Used :

D = down payment which a buyer can afford. There are many possible choices, but nine feasible choices from \$1,000 to \$5,000 with \$500 increments are represented on Table 2.3.

a = monthly payment which a buyer would pay for the next 25 years for the first cost of the home.

a = {(the first cost)-(down payment)} x (uniform series worth of a present sum)

$$= (\$19{,}720-D)\times\left(\frac{a}{p}\right)^{0.833\%}_{300\text{ months}}$$ (see Table 2.3)

t = property taxes

s_1 = monthly savings through the first three years (except the very first month)*. These monthly savings may be recovered by the net rental income of the one bachelor suite.

s_2 = monthly savings needed to meet the FLEXI-GROW No. 2, No. 3, and No. 4 additions. These monthly savings represent a uniform amount for a ten year period starting the first month of the fourth year.

F_i = FLEXI-GROW No. i, i = 1,2,3 and 4

$(\frac{a}{p})_n^i = \frac{i(1+i)^n}{(1+i)^n-1}$ uniform series worth of a present sum with interest rate i for n periods

$(\frac{f}{a})_n^i = \frac{(1+i)^n-1}{i}$ future worth of a uniform series with interest rate i for n periods

$(\frac{p}{f})_n^i = \frac{1}{(1+i)^n}$ present worth of a future sum with interest rate i for n periods

$(\frac{f}{p})_n^i = (1+i)^n$ future worth of a present sum with interest rate i for n periods

$(\frac{p}{a})_n^i = \frac{(1+i)^n-1}{i(1+i)^n}$ present worth of a uniform series with interest rate i for n periods

Payment Schedules

There are several choices which depend on a buyer's savings, income and expenditures, in deciding the payment schedule for the first

---

*To give one month lead time in order to rent the bachelor suite, the very first month is excluded.

Table 2.3

Feasible Down Payments and Monthly Payments

Over 25 Years for the First Cost of the Home ($19,720)

Down Payments D	The first cost - Down payment $19,720 - D	Uniform series worth of a present sum $(a/p)^{0.833\%}_{300\text{Month}}$	Monthly Payments a
$1,000	$18,720	0.00916	$171.48
1,500	18,220	0.00916	166.90
2,000	17,720	0.00916	162.32
2,500	17,220	0.00916	157.74
3,000	16,720	0.00916	153.16
3,500	16,220	0.00916	148.58
4,000	15,720	0.00916	144.00
4,500	15,220	0.00916	139.42
5,000	14,720	0.00916	134.84

cost of $19,720 for the basic floor plan as represented in Table 2.3. The chosen amount of the down payment for illustrative purposes is $2,000, which is approximately one-half of the average down payment ($3,800) of NHA borrowers during 1971. This down payment results in a monthly payment of $162.32 over the next 25 years (see Table 2.3).

The chosen model with the bachelor suite included in the basic floor plan may be a focusing point with respect to the payment schedule. The bachelor suite income will be saved through the first three years (except for the very first month). Net rental income after

tax from the bachelor suite and the total amount of the savings at the end of year three are as follows;

Net rental income = gross rental income - income tax*

= \$110/month - \$31.30/month

= \$78.70/month

The total amount of the savings at the end of the year three

$$= (\text{net rental income per month}) \times (f/a)^{0.5\%}_{35 \text{ months}}$$

$$= \$78.70/\text{month} \times 38.145$$

$$= \$3{,}002.00$$

Five hundred dollars for the first FLEXI-GROW addition in the year three will be payed with the money which is accumulated through the first three years by monthly saving S_1, \$78.70/month.

$$\$3{,}002.00 - F_1 = \$3{,}002.00 - \$500.00 = \$2{,}502.00$$

After the buyer pays \$500 for F_1, he has still \$2,502 in savings. The savings (2,502) will be useful for the following FLEXI-GROW additions F_2, F_3 and F_4. To decide on the required savings over the next 10 years for the FLEXI-GROW F_2, F_3 and F_4, the following calculations are required.

Present equivalent cost (PEC) at the end of year three for F_2, F_3 and F_4;

$$\text{PEC} = F_2 \times (\tfrac{p}{f})^{6\%}_{4 \text{ yrs}} + F_3\, (\tfrac{p}{f})^{6\%}_{7 \text{ yrs}} + F_4\, (\tfrac{p}{f})^{6\%}_{10 \text{ yrs}}$$

$$= \$3{,}436 \times 0.7921 + \$1{,}815 \times 0.6651 + \$2{,}857 \times 0.5584$$

$$= \$2{,}721.65 + 1{,}207.15 + 1{,}595.35$$

$$\cong \$5{,}524$$

---

*See Appendix C

The uniform amount of monthly savings required over the next ten years from the first month of year four;

$$S_2 = (\text{PEC - the savings at the end of year 3}) \times (\frac{a}{p})^{0.5\%}_{120\text{ months}}$$

$$= (\$5,524 - \$2,502) \times 0.0111$$

$$= \$3,022 \times 0.0111$$

$$\cong \$33.50$$

The FLEXI-GROW No. 2 addition costing $3,436 will be payed from the savings which are accumulated over the previous four years.

The expected total savings at the end of year seven;

$$\$33.50 \times (\frac{f}{a})^{0.5\%}_{48\text{ months}} = 33.50 \times 54.098 = \$1,812$$

$$\$2,502 \times (\frac{f}{p})^{6\%}_{4\text{ yrs}} = 2,502 \times 1.262 = \$3,157$$

Total $4,969

The balance of the savings after the payment for F_2;

$$\$4,969 - F_2 = \$4,969 - \$3,436 = \$1,533$$

The FLEXI-GROW No. 3 addition costing $1,815 may also be payed with the savings which are accumulated from the first month of year eight to the end of year ten.

The expected total savings at the end of year ten;

$$\$33.50 \times (\frac{f}{a})^{0.5\%}_{36\text{ months}} = 33.50 \times 39.336 = \$1,318$$

$$\$1,533 \times (\frac{f}{p})^{6\%}_{3\text{ yrs}} = 1,533 \times 1.191 = \$1,826$$

Total $3,144

The balance of the savings after the payment for F_3;

$\$3,144 - F_3 = \$3,144 - \$1,815 = \$1,329$

The final FLEXI-GROW addition (F_4) of \$2,857 may occur in the year 13, the cost \$2,857 will be payed with the savings accumulated up to the end of year 13.

The expected total savings at the end of year 13;

$$\$33.50 \times (\tfrac{f}{a})^{0.5\%}_{36\ months} = 33.50 \times 39.336 = \$1,318$$

$$\$1,329 \times (\tfrac{f}{p})^{6\%}_{3\ yrs} = 1329 \times 1.191 = \$1,583$$

Total $\$2,901$

The balance of the savings after the payment for F_4;

$\$2,901 - F_4 = \$2,901 - \$2,857 = \$44$

Each payment and required savings which are explained above is represented on one cash flow diagram Figure 2.15, which shows the down payment, the monthly payment, the property tax, the required savings, and the costs of each addition (F_1, F_2, F_3 and F_4). Figure 2.16 represents the net total monthly payments to be required over the 25 year period. The monthly payments which should be invested for the chosen FLEXI-GROW housing model increased at the end of year three from \$202.32 per month to \$235.82 per month and decreased at the end of year 13 from \$235.82 per month to \$202.32 per month.

Calendar Year Year n	1971 0	'74 3	'78 7	'81 10	'84 13	'96 25
Down payment plus each FLEXI-GROW addition	$2,000	$500	$3,436	$1,815	$2,857	
Monthly payments including interest	$162.32/month (year 0 to year 25)					
Property tax	$40.00/month (year 0 to year 25)					
Monthly savings	$78.70/M (year 0 to year 3)	$33.50/month (year 3 to year 13)				
Rental income after tax	$78.70/M (year 0 to year 3)					

Figure 2.14 Payments and savings for the FLEXI-GROW No. 2 Model

2.4.4 Comparison Study of the Chosen Model with a Conventional Housing System

In a conventional home (conventional refers to present day on-site construction) changes in the original floor plan or an extension to the original home at some future date is not impossible, but it is expensive and usually not considered.

To compare total costs and payment schedules between the FLEXI-GROW housing system and a conventional housing system, the following example is presented.

The size of the home: 1,248 ft^2 including three bedrooms and a family room, double garage, and patio.

The home is assumed to be purchased in year eight (1979).

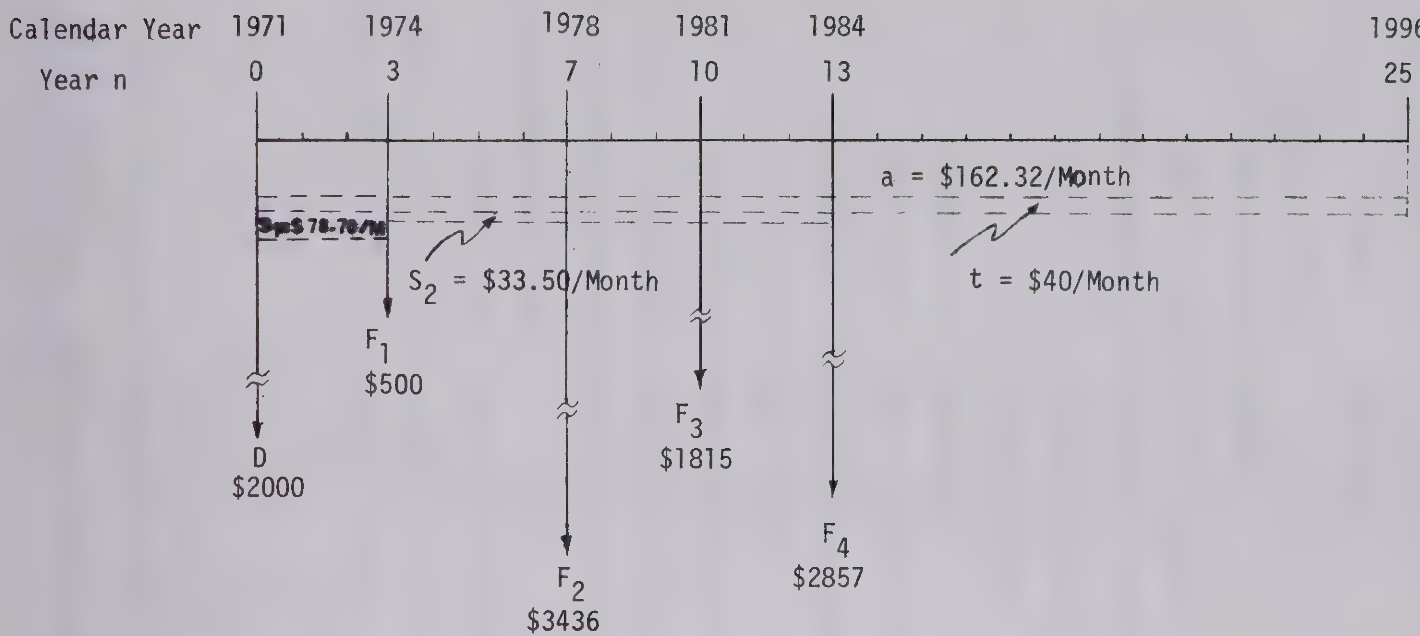

Figure 2.15 Down payment, monthly payment, property tax, and savings for the chosen model

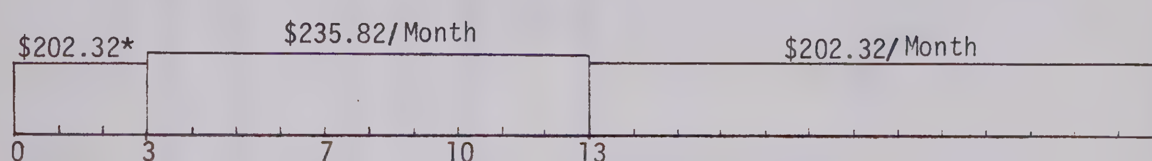

Figure 2.16 Net total monthly payments to be required after the first down payment for the chosen model

*202.32 = a + t = 162.32 + 40

The cost of the home:

Land cost = \$ 7,605*

Building cost = 27,279 ($1248ft^2 x 20.35/ft^2 + 1713.40 + 169$)*

Total \$34,834

Payment schedules:

Down payment = \$3,800**

Monthly payment; uniform amounts for 25 years

$$\text{Monthly payment (a)} = (34{,}884 - 3{,}800)(a/p)^{0.833\%}_{300\ \text{months}}$$

$$= 31{,}084 \times 0.00916$$

$$= \$\ 284.73/\text{month}$$

Property tax = \$40/month

Total monthly payment = \$324.73/month

Family size of buyer***; one couple and two children,

husband's age is assumed to be 33 years

Total monthly payment schedules for the chosen FLEXI-GROW home and a conventional home which has the same floor area as the FLEXI-GROW home are represented by Figure 2.17. These two houses are compared as follows:

1. The total cost which is estimated to be payed for each house is computed, on the basis of the total present equivalent cost (PEC) in the year in which the first payment occurs.

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*See Table 2.1.
**The average down payment cost of NHA borrowers at 1971.
***See Figure 2.1 and 2.2

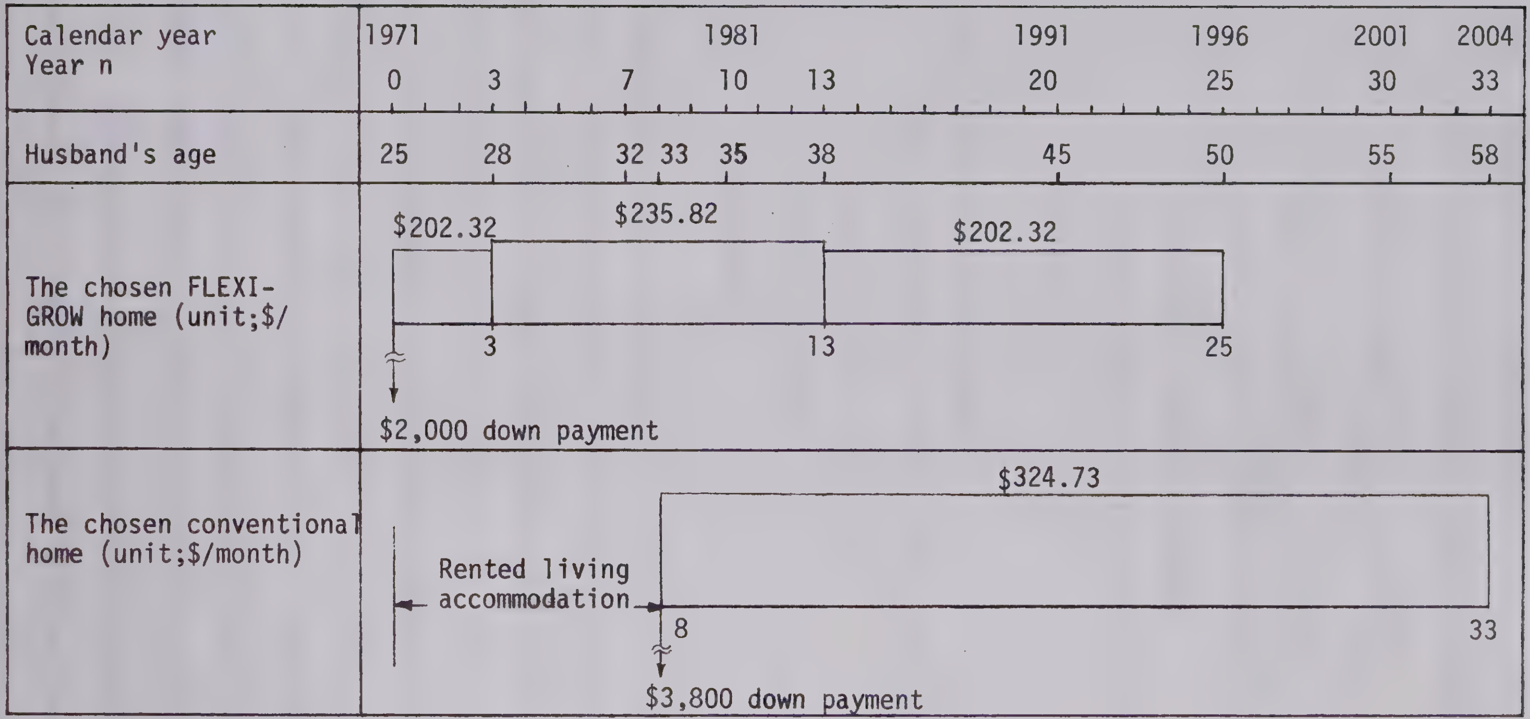

Figure 2.17 Total monthly payment schedules for the chosen FLEXI-GROW home and the chosen conventional home

1-1 The chosen FLEXI-GROW house;

$$\text{PEC at the year } 0 = 2{,}000 + 202.32\ (p/a)^{0.5\%}_{36\text{ months}}$$

$$+ 235.82\ (p/a)^{0.5\%}_{120\text{ months}}\ (p/f)^{6\%}_{3\text{ yrs.}}$$

$$+ 202.32\ (p/a)^{0.5\%}_{144\text{ months}}\ (p/f)^{6\%}_{13\text{ yrs.}}$$

$$= 2{,}000 + 202.32 \times 32.871 + 235.82 \times 90.073 \times 0.8396$$

$$+ 202.32 \times 102.451 \times 0.4688$$

$$= 2{,}000 + 6{,}650.46 + 17{,}833.96 + 9{,}717.23$$

$$\cong 36{,}202$$

1-2 The conventional house;

$$\text{PEC in the year } 8 = 3{,}800 + 324.73\ (p/a)^{0.5\%}_{300\text{ months}}$$

$$= 3{,}800 + 324.73 \times 155.207$$

$$= 3{,}800 + 50{,}400$$

$$= \$54{,}200$$

As shown by the above calculations, using 6% as a basis for the cost of money, a present equivalent of $36,202 is estimated to be payed over 25 years for the chosen FLEXI-GROW house, but a present equivalent of $54,200 is estimated to be payed over 25 years for the conventional house. The down payment and the monthly payments of the chosen FLEXI-GROW house are also less than those of the conventional house.

2. With respect to the huband's age, the conventional house requires house payments up to the age of 58 years, but in the case of the FLEXI-GROW house payments are required only to age 50.

3. The conventional house represents the most common payment style to date. This requires that most families rent for the first eight years. The chosen FLEXI-GROW home should eliminate the inconvenience and non-recoverable losses due to renting.

4. Past experience indicates that construction and land costs will increase every year, therefore, the earlier purchase of a home becomes more desirable.

2.5 Effectiveness of the FLEXI-GROW Housing System

The effectiveness of the FLEXI-GROW housing system may be measured by various parameters. Two basic parameters are discussed below:

2.5.1 Direct effect on the housing problem;

1. The origin of the family formation is the marriage. The FLEXI-GROW housing system offers an answer to the housing problem at the beginning point of the family formation. It should be truly functional for raising a family.

2. The total investment cost of the FLEXI-GROW housing system is more economical than most other housing systems. This housing system should appeal to all income levels,and more specifically to low income levels.

3. Flexibilities of floor plans should satisfy the changing demands of any size of family.

4. The FLEXI-GROW housing system should help the number of non-family householders which are increasing every year.

5. This housing system also allows most families to own their own homes immediately on marriage. This possibility reduces the number of times the family will have to move.

2.5.2 Indirect effect on society

1. The FLEXI-GROW housing system should promote savings by young families.

2. Payments can be completed earlier than payments on conventional housing systems. This system should allow the family to save more money for retirement.

3. Perhaps, the major effect to be considered is the reduction in the number of moves the family now has to make. This point will be discussed in the next section in detail.

2.5.3 The FLEXI-GROW housing system and Family Relocation;

Most people desire to remain in the same home rather than move from home to home.

1. What types of families move most often?

   1-1 Where the ages of heads of households are under 35 years, the number of movers are more than the number of non-movers, but where this age is above 35 years, the number of movers are much less than the number of non-movers [21].

   1-2 Renters are considerably more mobile than owners, and renters who prefer to own their home are considerably more mobile than renters preferring to rent [21].

   1-3 Most renters who are full families (both parents and unmarried children present) want to move [21].

The FLEXI-GROW housing system should appeal to the most frequent movers, and it should reduce the number of movers.

2. Why or under what circumstances do families move?

There are so many reasons why families move, however, the following two reasons are considered as the most frequent reasons [21].

2-1 An increase in family size leads to a higher level of mobility desires among renters.

2-2 Most frequently given sources of complaints about housing are considered to be characteristics of the dwelling unit itself, for instance, amount of space within the dwelling, the number of rooms, closets etc.

The FLEXI-GROW housing system offers a functional approach to an increase in family size and the amount of space desired within the dwelling.

CHAPTER III

THE DESIGN OF THE FLEXI-GROW HOUSING COMPONENTS

3.1 The Wall System

The wall system has been designed to satisfy the requirements of the FLEXI-GROW housing system. This wall system allows considerable flexibility to alter the floor plan as the family desires.

Specification Requirements of the Desired Wall System

The wall system chosen should be of sufficiently high quality to promote:

1. Easy installation or removal of wall sections without disturbing the remainder of the wall;

2. Favorable acceptance, both economically and aesthetically, to the buyer with an absolute minimum of final finishing on the building site;

3. Interchangeability between wall sections to be joined;

4. Flexibility in manufacturing from a large number of building materials;

5. Trouble free tolerances and ruggedness to withstand shipment over fairly large distances; and

6. Handling and assembly by inexperienced personnel on the building site.

The Chosen Design

The prefabricated panel system in which the wall sections are manufactured in the factory and assembled on the site with wall locking mechanism was selected to meet the above requirements.

3.1.1 Wall Locking Mechanism

In order for the exterior and the interior walls to offer the flexibility desired a suitable connecting and locking mechanism for these walls has been developed. This connecting and locking mechanism should allow all panels to be readily removed to meet the changing demands of the tenant. In this manner the extension of an exterior wall or partial exterior wall becomes an easy job and the movement of interior panels to convert the interior, for example, from a two bedroom to a three bedroom home becomes quite realistic.

The chosen design was selected for its simplicity and flexibility in the connection of two adjoining wall panels to a studding framework.

There are three basic connections to contend with in the construction of a home. They are: (1) the wall panel connection, (2) the corner connection, and (3) the butt-end connection. Schematic drawings of the first two sections and the third section are shown in Figure 3.1 and Figure 3.2 respectively.

Each one of these connections utilize the same basic principles of design. The studding framework shown, for illustrative purposes in Figures 3.1, 3.2 and 3.3 is circular and can be made of various materials such as steel or reinforced plastics. There are several advantages in the final design selected such as:

1. The studding framework to which the panels are connected is not limited to any specific cross-sectional area.

2. The design promotes flexibility because exterior wall panels are interchangeable, interior wall panels are interchangeable, corner

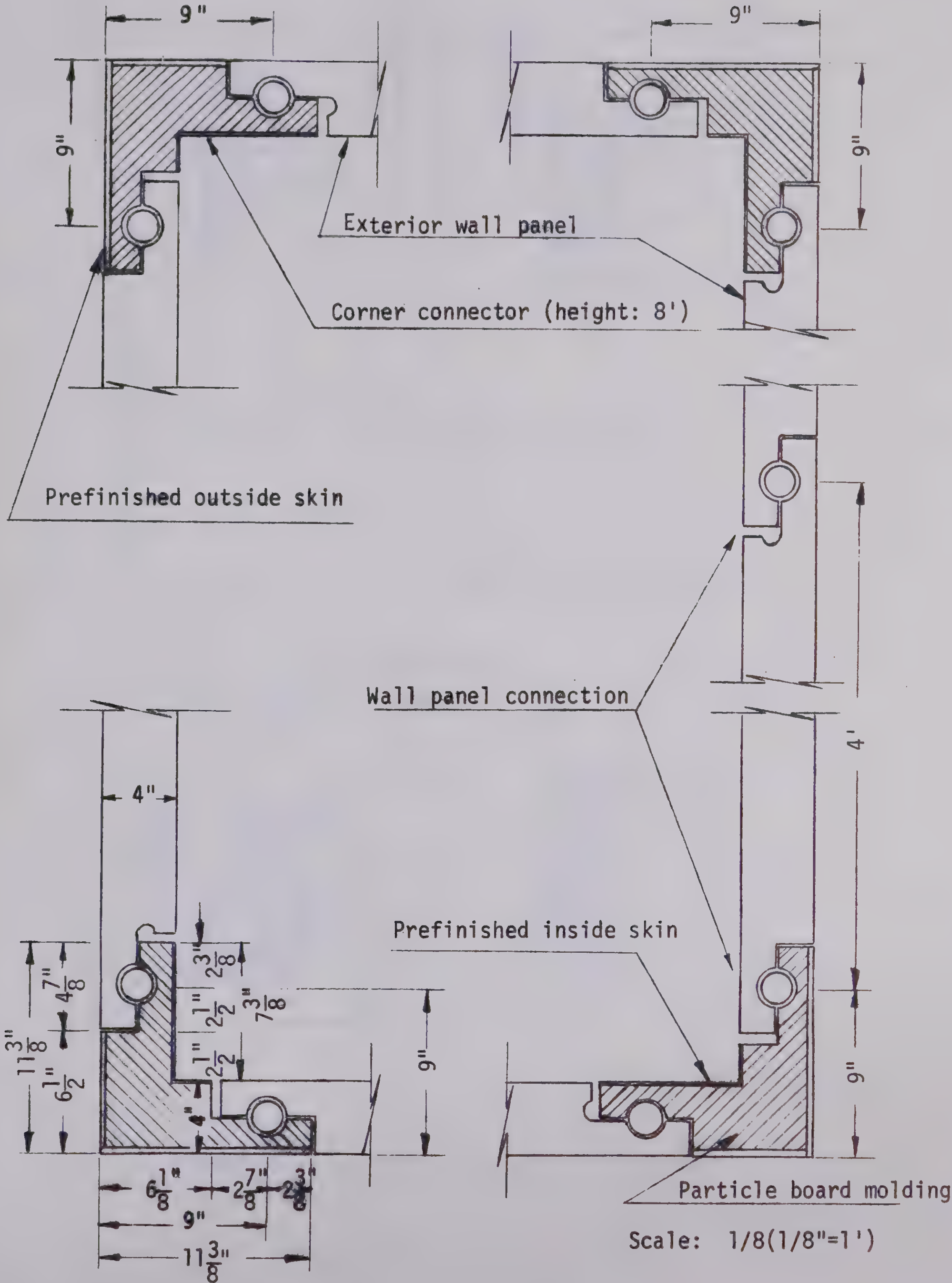

Figure 3.1 Top view of wall panel and corner connection

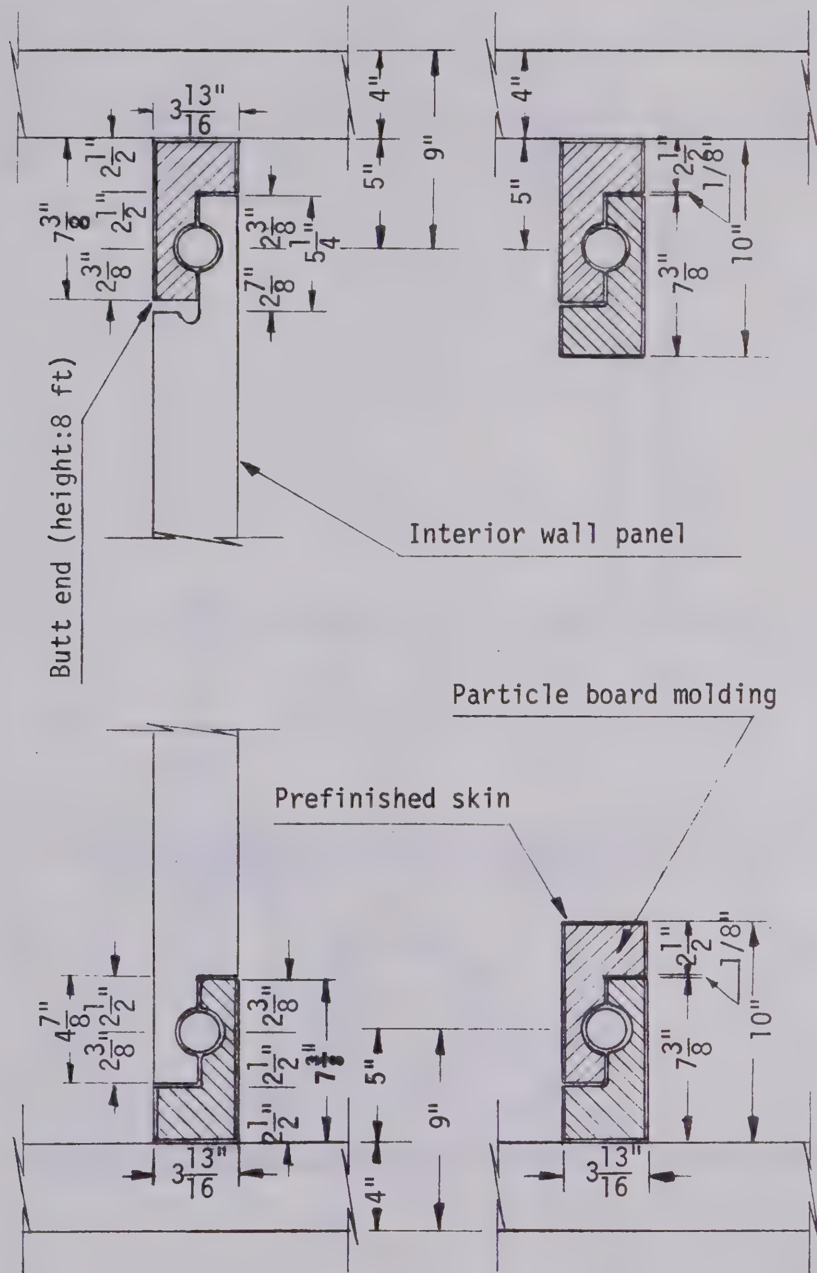

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Figure 3.2 Top view of butt-end connection

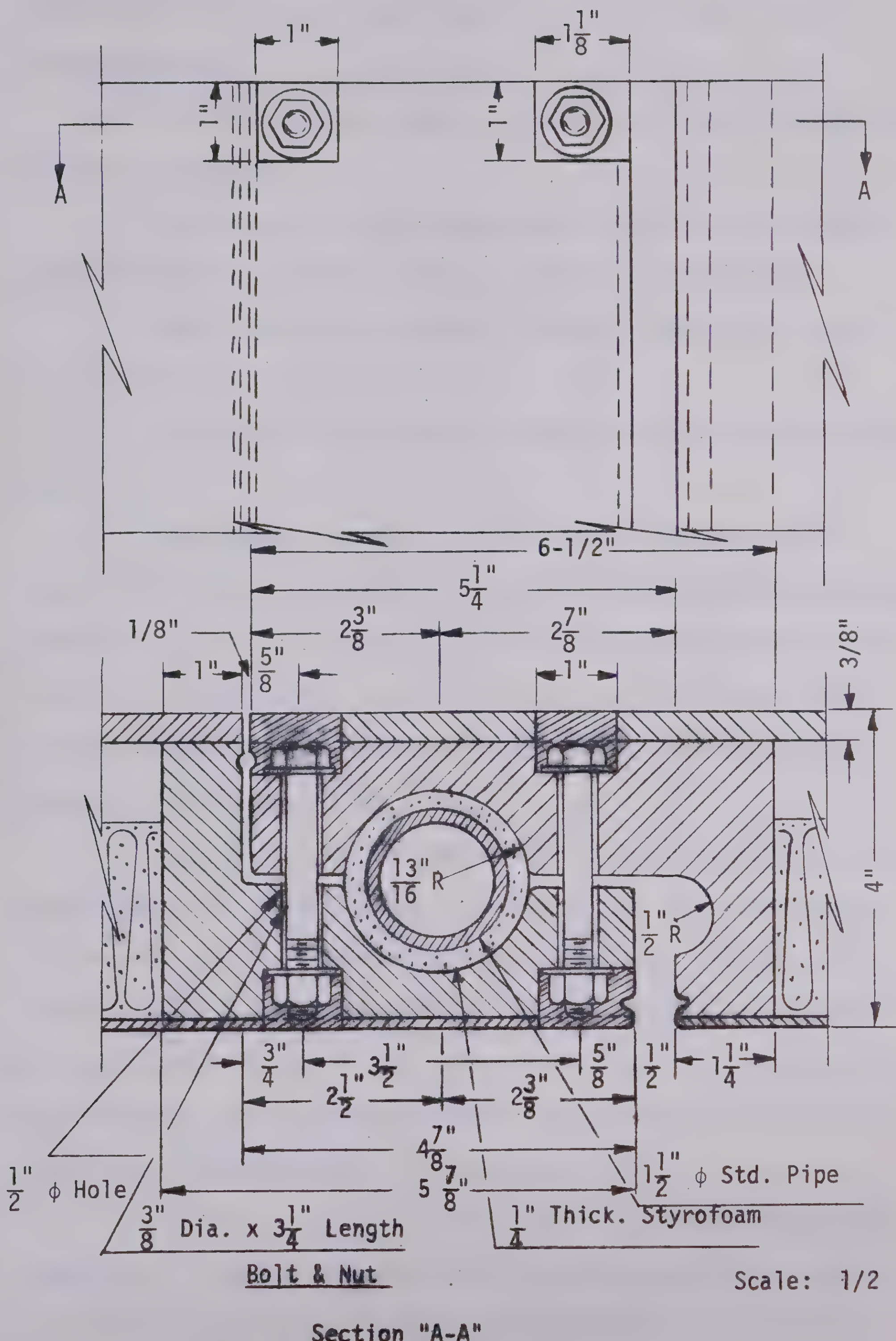


Figure 3.3 Wall Panel Connection

connections are interchangeable and all butt-end connections are interchangeable.

3. The same equipment can be used in the factory to manufacture all three sections.

4. The connections can be manufactured from a fairly broad range of materials such as plastics, plywood and chipboard.

5. Wall panels can be readily removed to add to or change the basic design of the home.

6. The panels can be readily installed on site by inexperienced personnel.

The connections allow a great deal of flexibility in respect to a locking mechanism. Figure 3.3 shows the locking mechanism that would be suitable and easily installed on the location. An insulating air-tight seal can be readily installed around the wall studding member. The panels will be thoroughly secured by being bolted at the top and at the base.

The end join between two panels will be sealed with a sealing compound and a plastic cap installed for an appealing finish. A piece of insulation material will be put on the bolt head or nut and a piece of outside skin will be covered with sealing compound for the outside surface of the exterior wall panel. A plastic strip will be glued over the inner surface at the top and at the base to cover the locking mechanism. (See Figure 3.4).

Figure 3.5 shows the finishing of the interior wall panel connection. A sealing compound and a plastic cap will be used for the finish of the joint. A plastic strip will be glued over both surfaces at the top and at the base. The insulation material and

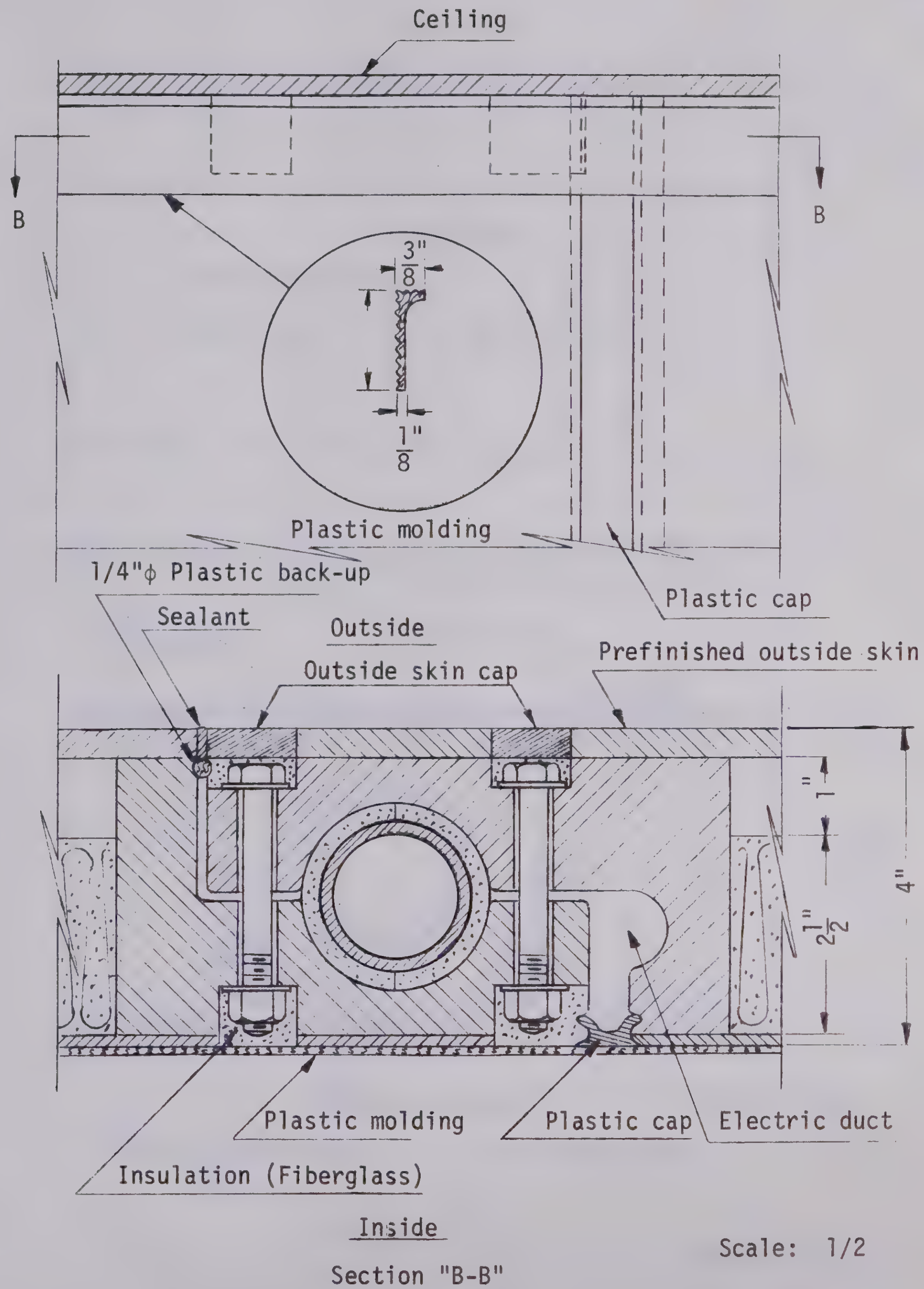
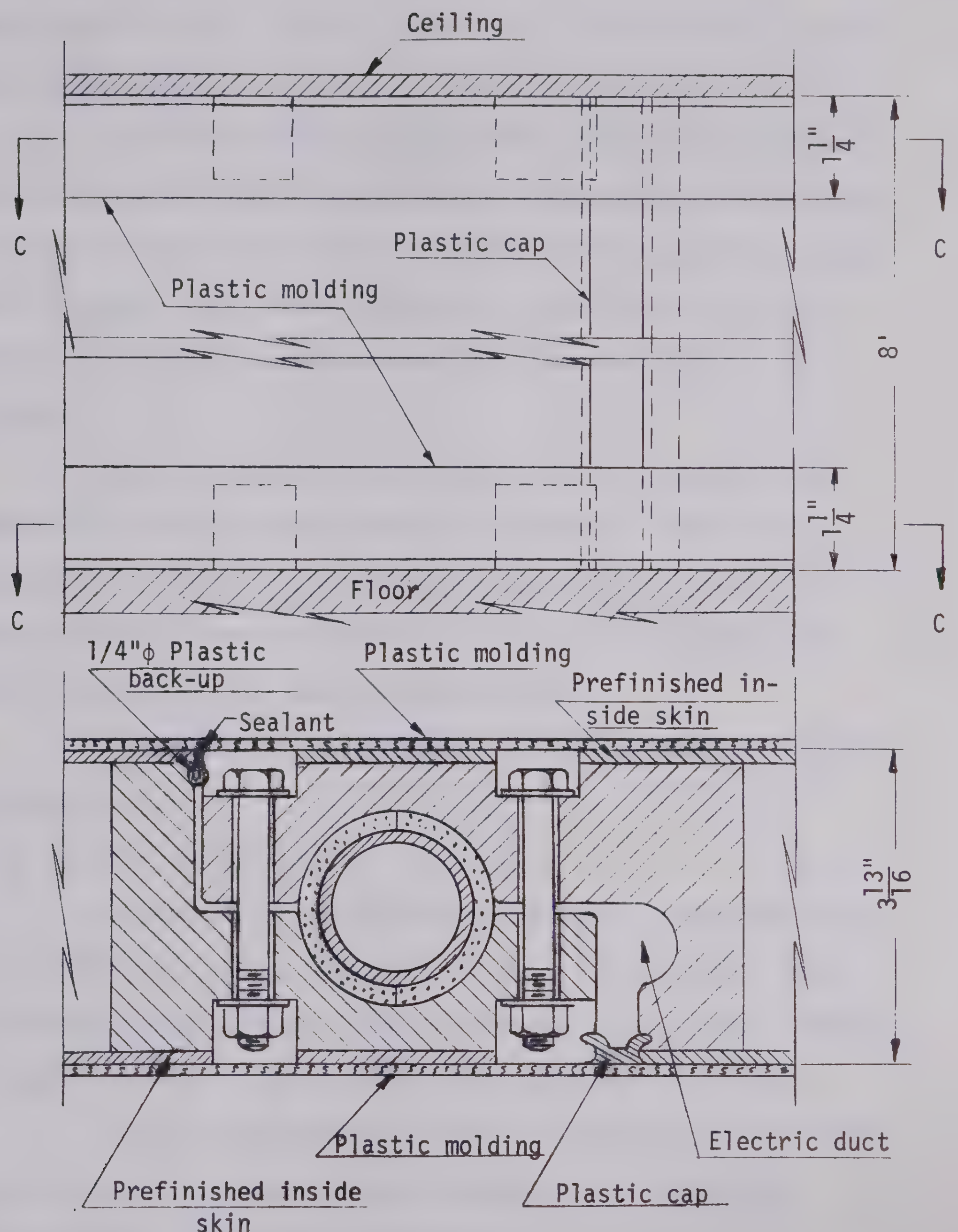


Figure 3.4 Finishing of the exterior wall panel connection



Section "C-C"

Scale: 1/2

Figure 3.5 Finishing of the interior wall panel connection

sealing material over the bolt heads are not necessary for the interior wall finish.

The electric duct which is shown on the drawings allows the installation of the electric wire. The plastic cap which covers the electric duct can be installed easily and also removed without any difficulty. This gives reasonable flexibility to the initial electric wiring and possible repair after the wall panels are finished.

The same locking mechanism is used for connecting the exterior wall panels as the interior wall panels. This locking mechanism allows the wall panels to be completely finished within the factory except for the installation of the sealing compound and plastic strips over the joint on the location.

Alternative panel locking mechanisms studied are presented in Appendix D.

3.1.2 Exterior Wall Panels

Exterior wall panels have been designed to meet the requirements stated previously. The exterior walls can be readily moved to vary the available floor space as desired. This allows a family to expand the size of the dwelling to accommodate their needs.

The chosen exterior wall panel was selected for its simplicity and flexibility with respect to manufacturing, handling, transportation, installation and removal.

The chosen size of panels will be assembled and finished in the factory and installed with the locking mechanism on site. The surface of the panel skin is readily finished by coating or plastic lamination. Two wood end studs with the chosen sectional

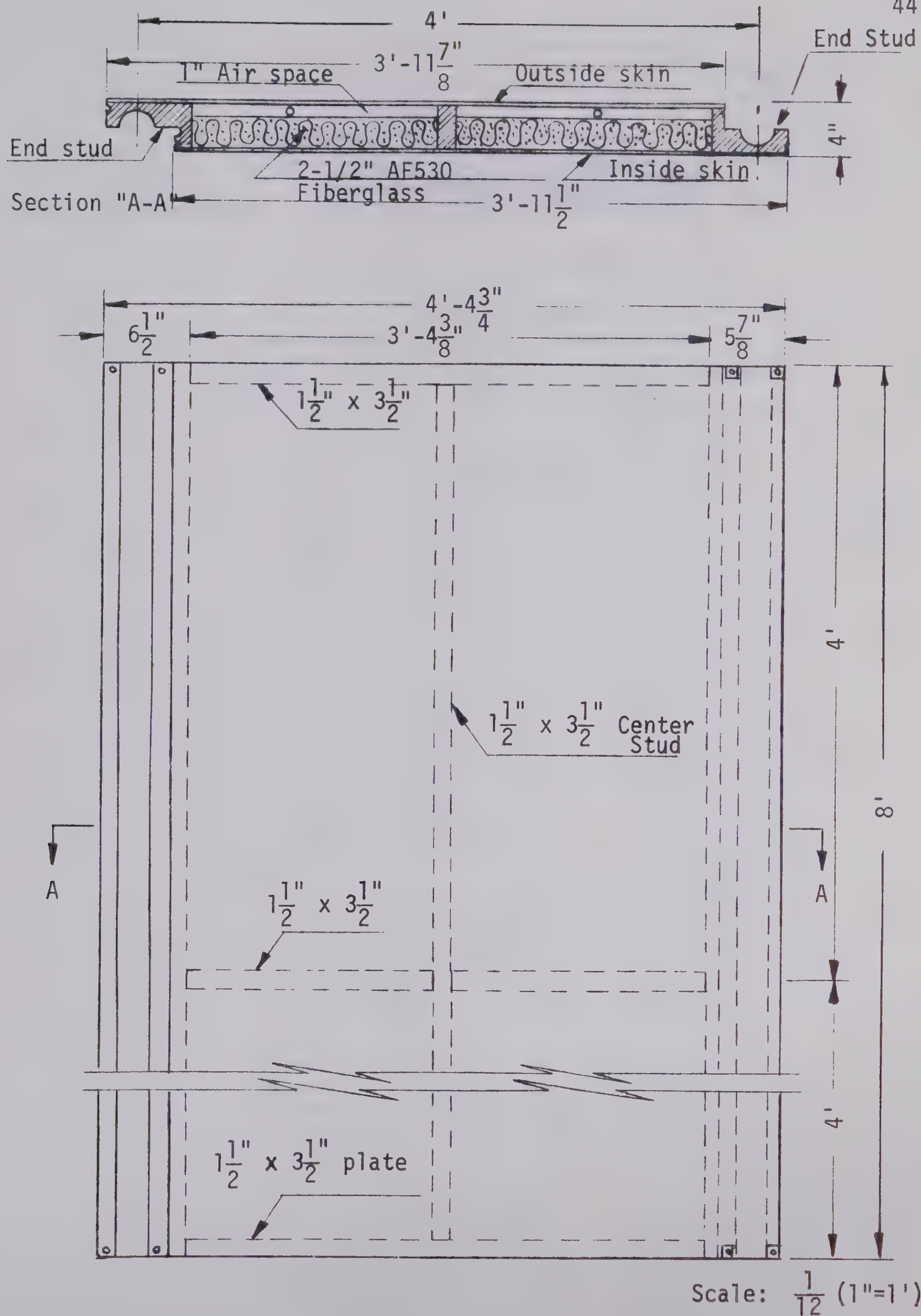
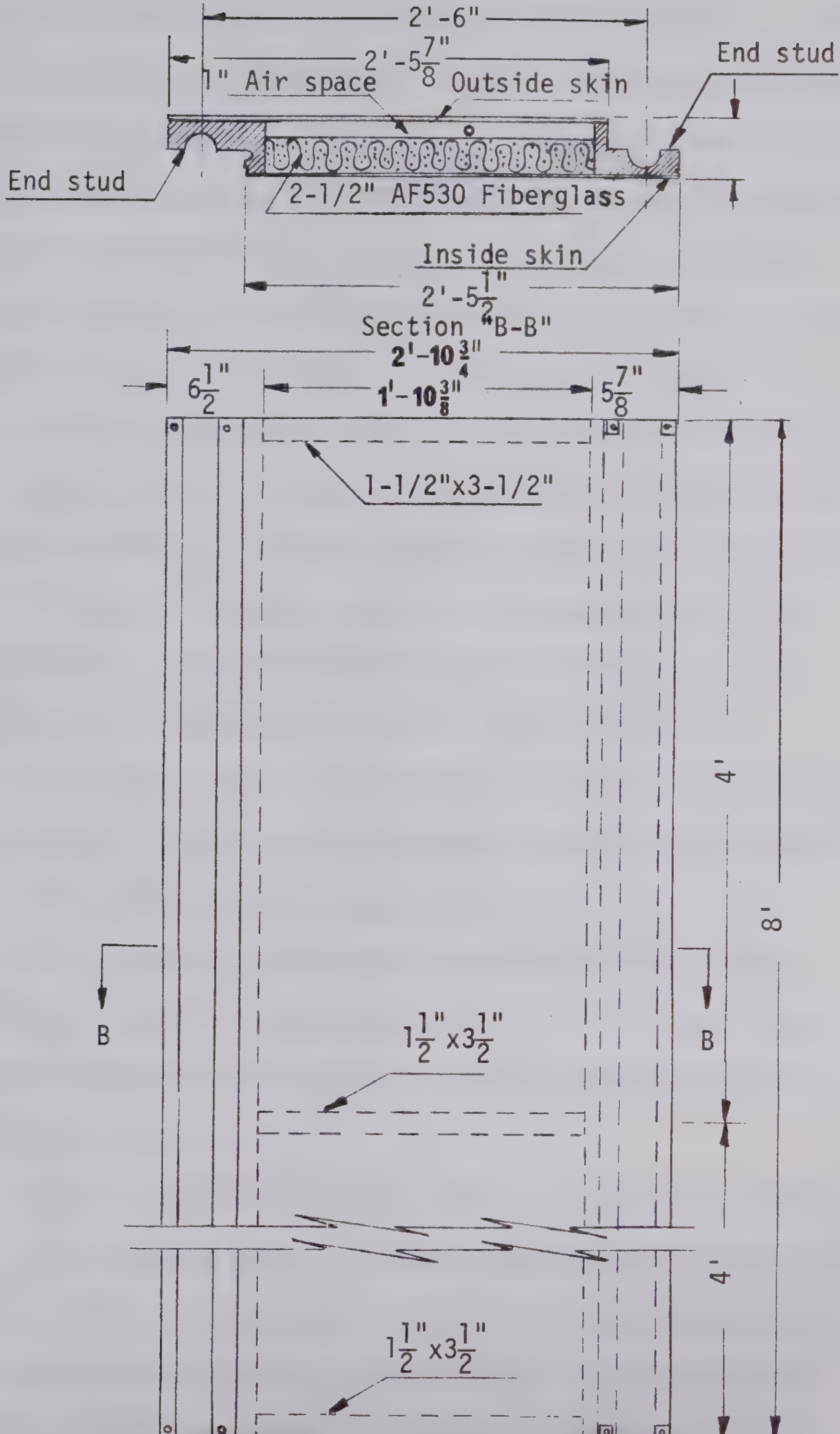


Figure 3.6 The four foot exterior wall panel



Scale: $\frac{1}{12}$ (1"=1')

Figure 3.7 The two foot six inch exterior wall panel

view are used at each end of a wall panel. These end studs will be used to connect the wall panels with the locking mechanism which was introduced in the previous section 3.1.1. Figure 3.6 shows the details of the four feet wide and eight feet high standard exterior wall panel. From a manufacturing standpoint it is ideal to make only one standard size of panel, but one standard size of panel can not give enough flexibility to the various floor plans desired. An auxiliary size for the exterior wall panel is shown in Figure 3.7. It is two feet-six inches in width and eight feet in height. The combination of these two different sizes of panels should give enough variety to the basic floor plans and possible extensions of the FLEXI-GROW house. One or two pieces of two feet-ten inch panels may be added for an extension of a house. (See Figure 3.36).

The chosen size of the center stud and the chosen thicknesses of the wall skins and the insulation material were selected to satisfy the national building code [18].

It is suggested that the end stud be made from particle board molding, because of its cross-section. If it is made from ordinary wood materials too much waste will be produced during the manufacturing process.

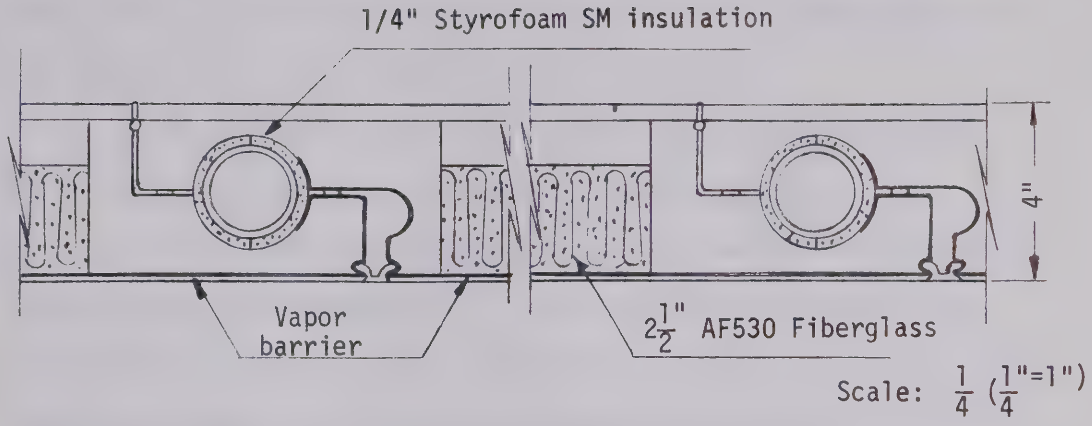
There are several different kinds of insulation materials available in the present market. These alternatives are represented in Table 3.1. The chosen insulation material for the exterior wall panel is two and half inch AF530 fiber-glass. This material was selected for its low cost, ease of handling, suitable size and rigidity for the panel. Another insulation material, styrofoam

Table 3.1

Insulation Materials Feasible for the Exterior Wall

Materials feasible for the exterior wall panel	Thermal conductivity "K" at 75°F	Required thickness	Vapor transmission with the required thickness	Density	Weight per unit area with the required thickness	Unit Cost	Total cost per 960 sq.ft. house	Total thermal resistance "R"
	BTU/hr./sq.ft./°F/in.	inches	perms**	lbs/cu.ft.	lbs/sq.ft.	$/1000 board-feet or sq. ft.	$	hr./sq.ft./°F./BTU
Styrofoam SM	0.20	2	0.30	2.20	0.336	150/MFBM	280	11.3
Styrofoam SE	0.26	3	1.00	1.00	0.25	105/MFBM	293	12.8
A.F. Home Insulation (Fiberglass) Flexible roll	0.35	$3\frac{1}{2}$	--	--	--	89/MSF	83	11.38
A.F. 110 Insulation (Fiberglass) Semi-rigid board	0.262	$2\frac{1}{2}$	--	1.10	0.23	67.5/MSF	63	10.9
A.F. 530 Insulation* (Fiberglass) Rigid board	0.25	$2\frac{1}{2}$	--	3.0	0.62	67.5/MSF	63	11.38

*Chosen material
**1 grain per (hour)(square foot)(inch of mercury vapor pressure difference)



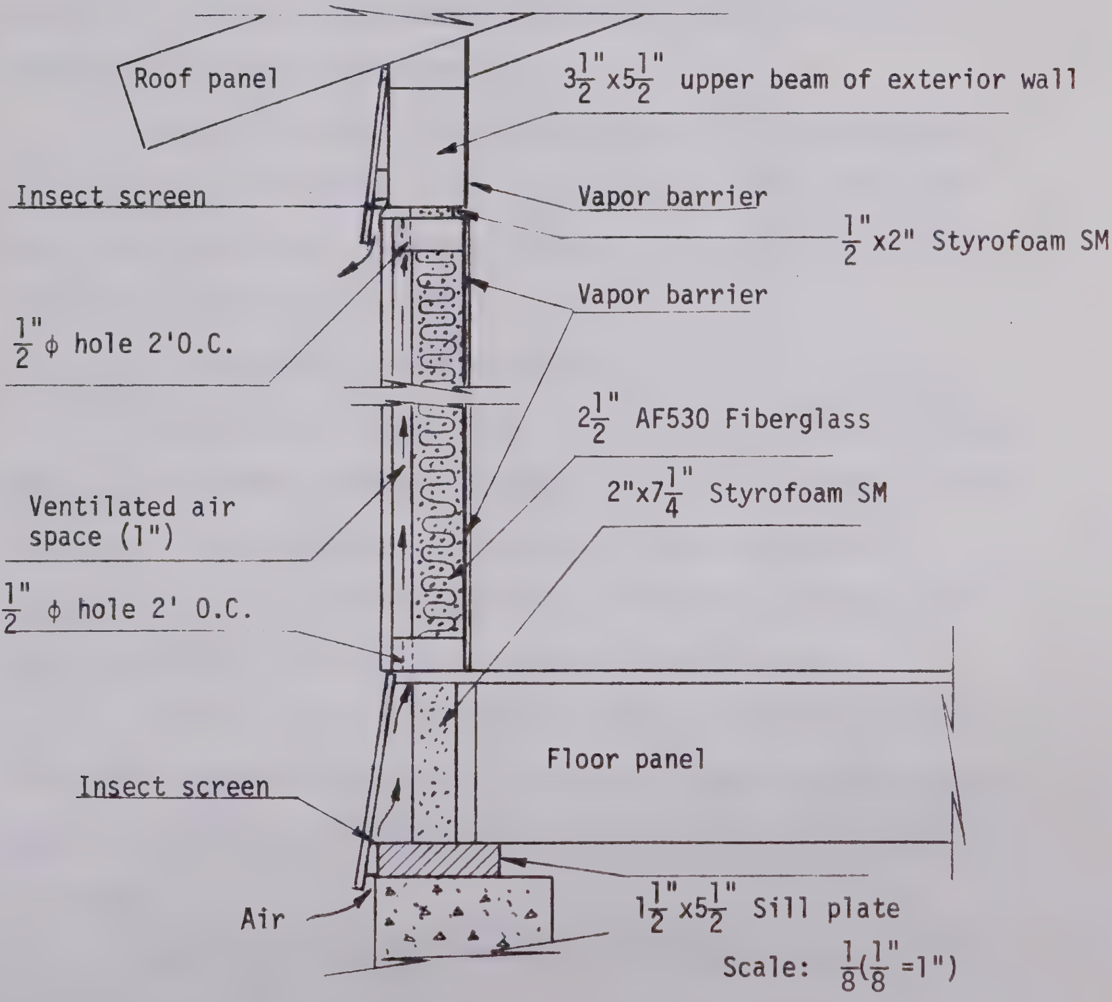


Figure 3.8 Air ventilation and vapor barrier in the exterior wall

SM, will be used for the studding framework and other auxiliary purposes such as, the installation of the exterior wall panels where AF 530 fiber-glass is not suitable. (See Figure 3.8).

The approximate weight of a four feet by eight feet exterior wall panel will be 129 pounds. (See Appendix E).

Air ventilation and vapor barrier in the exterior wall of a house should not be neglected. Closed stressed skin panels full of insulation cannot be vented effectively therefore one inch air space through the exterior wall panel is provided to allow air ventilation. Two mill (0.002") polyethylene can be used as a vapor barrier on the warm side of the insulation [16].

Figure 3.8 shows how air ventilation will be accomplished in the exterior wall panels after installation and where the vapor barrier will be put on. The vapor barrier will be installed in the factory when panels are assembled.

3.1.3 The Exterior Door and Window Panels

The basic style and size of exterior door panels and window panels are the same as those of standard exterior wall panels. Door and window frames were inserted between end studs, therefore, exterior door panels or window panels can be easily connected with any exterior wall panel and interchanged without trouble.

Figures 3.9 and 3.10 show the exterior door panel which is four feet in width and eight feet in height. Three feet wide and six feet-ten inch high exterior door and combination door were chosen [3 and 16].

There are three different sizes of window panels for the

FLEXI-GROW housing system. They are:

1. The window panel "L" for a large window,
2. The window panel "M" for a medium sized window and
3. The window panel "S" for a small window.

The window panel "L" was designed for use in the living room of the FLEXI-GROW house. The panel size is eight feet in width and eight feet in height. The window size is seven feet in width and three feet-six inches in height. The framing of the window panel "L" is represented in Figure 3.11. Figures 3.12 and 3.13 show the details of the window panel "L".

For bedrooms, kitchen and the dining room of a house the window panel "M" was designed. The size of the window panel "M" is four feet in width, eight feet in height, the same size as the standard exterior wall panel. This gives complete flexibility to the various floor plans and an extension or a change of the floor plan, because the window panel is interchangeable with any standard exterior wall panel. Figures 3.14 and 3.15 show the detailed design of the window panel "M". The window itself is a double-glazing and fixed type which is three feet - 3-1/8 inches in width and three feet in height. Air ventilation will be accomplished through the small swing openings which are installed just above and below the main window [23]. Insect screens remain installed the year around.

The window panel "S" is four feet in width and eight feet in height. It has the same design as the window panel "M" with a different window size. This panel will be used for bathrooms. (See Figure 3.16 and 3.17).

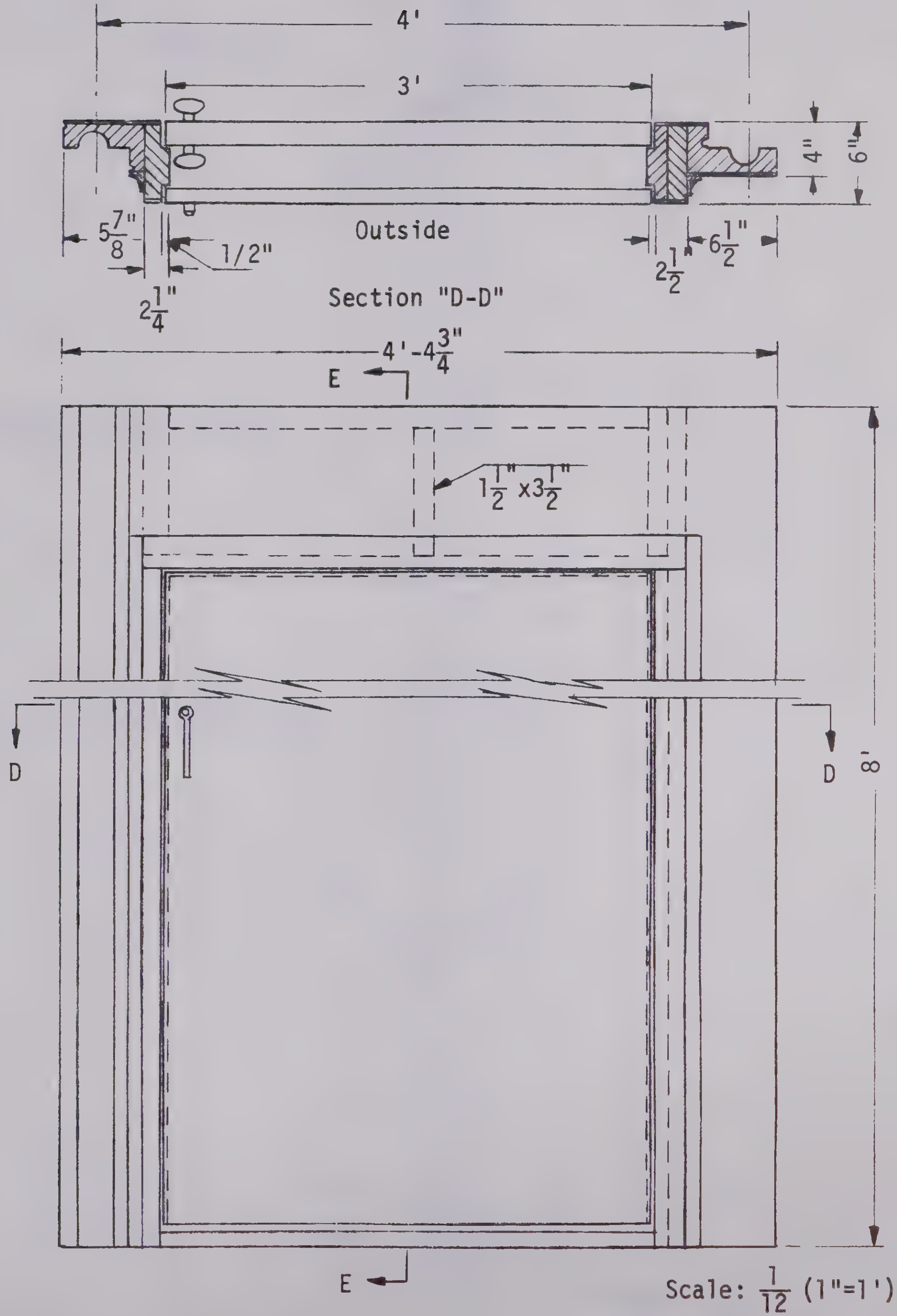


Figure 3.9 The exterior door panel

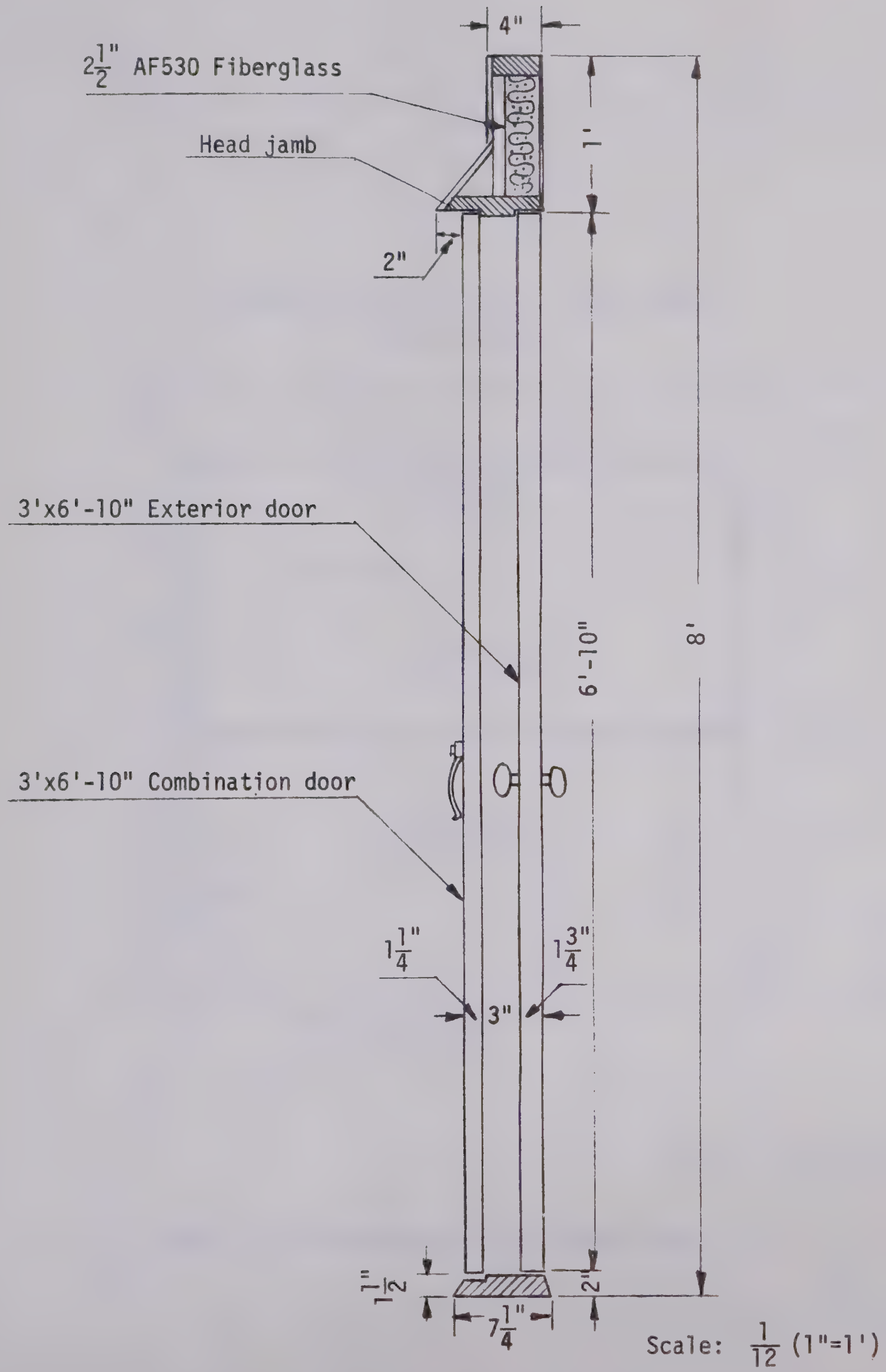


Figure 3.10 Section "E-E" of the exterior door panel

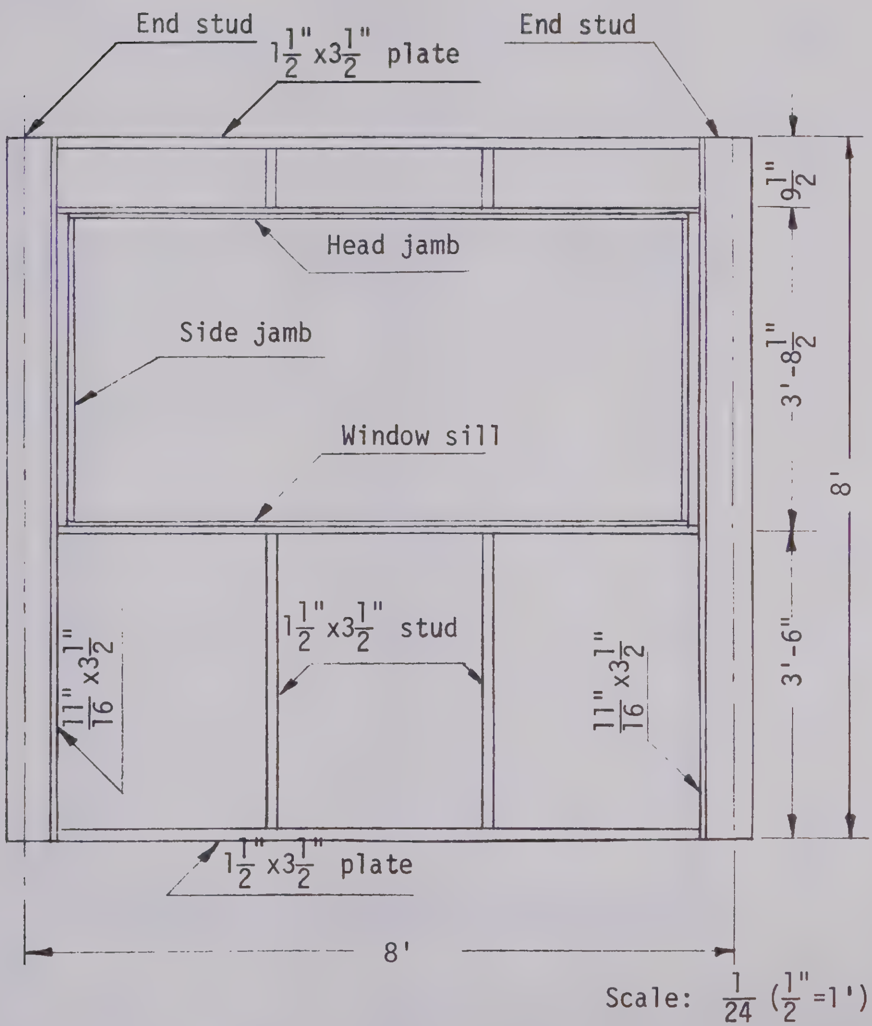


Figure 3.11 The Framing of the window panel "L"

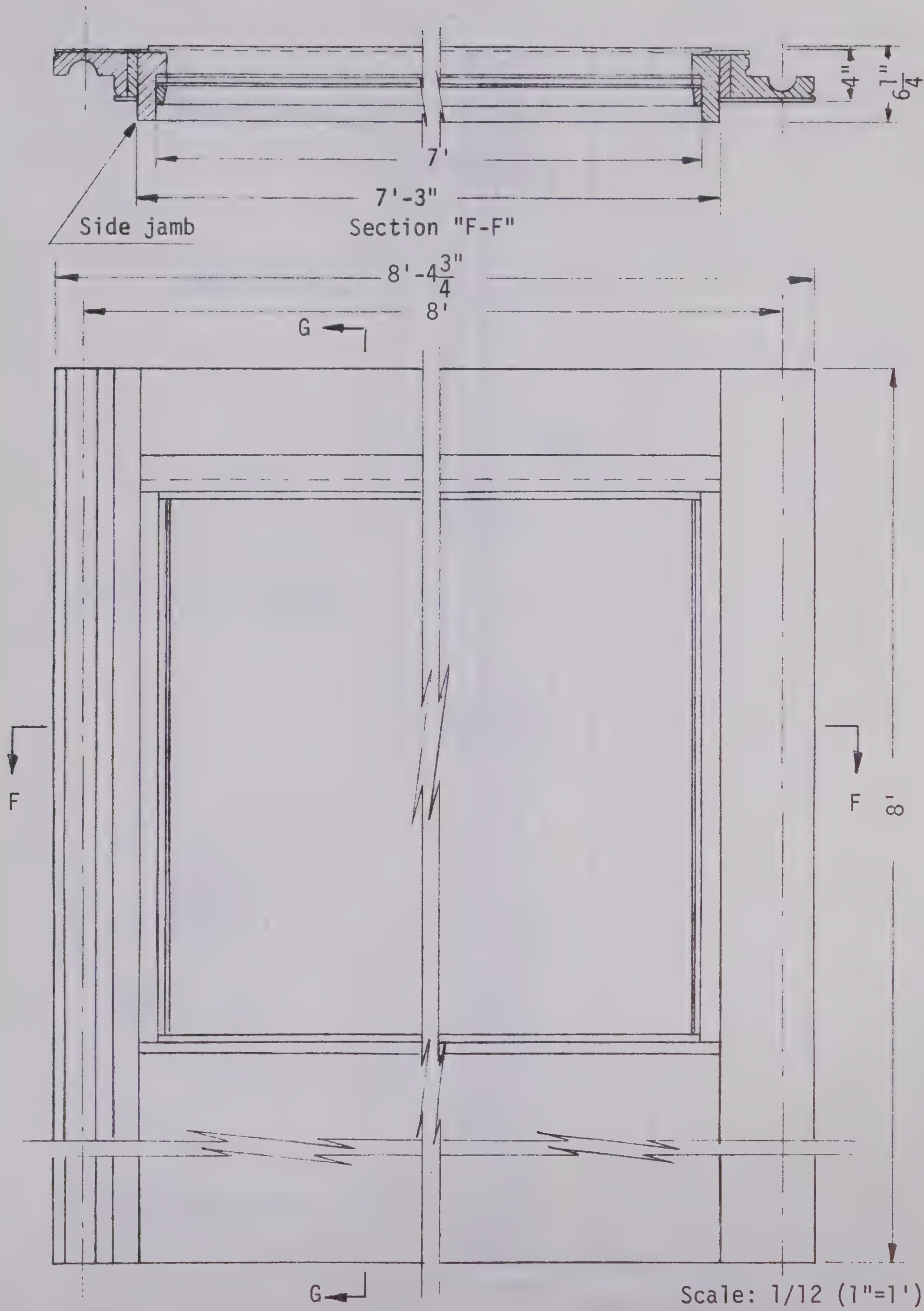


Figure 3.12 The window panel "L"

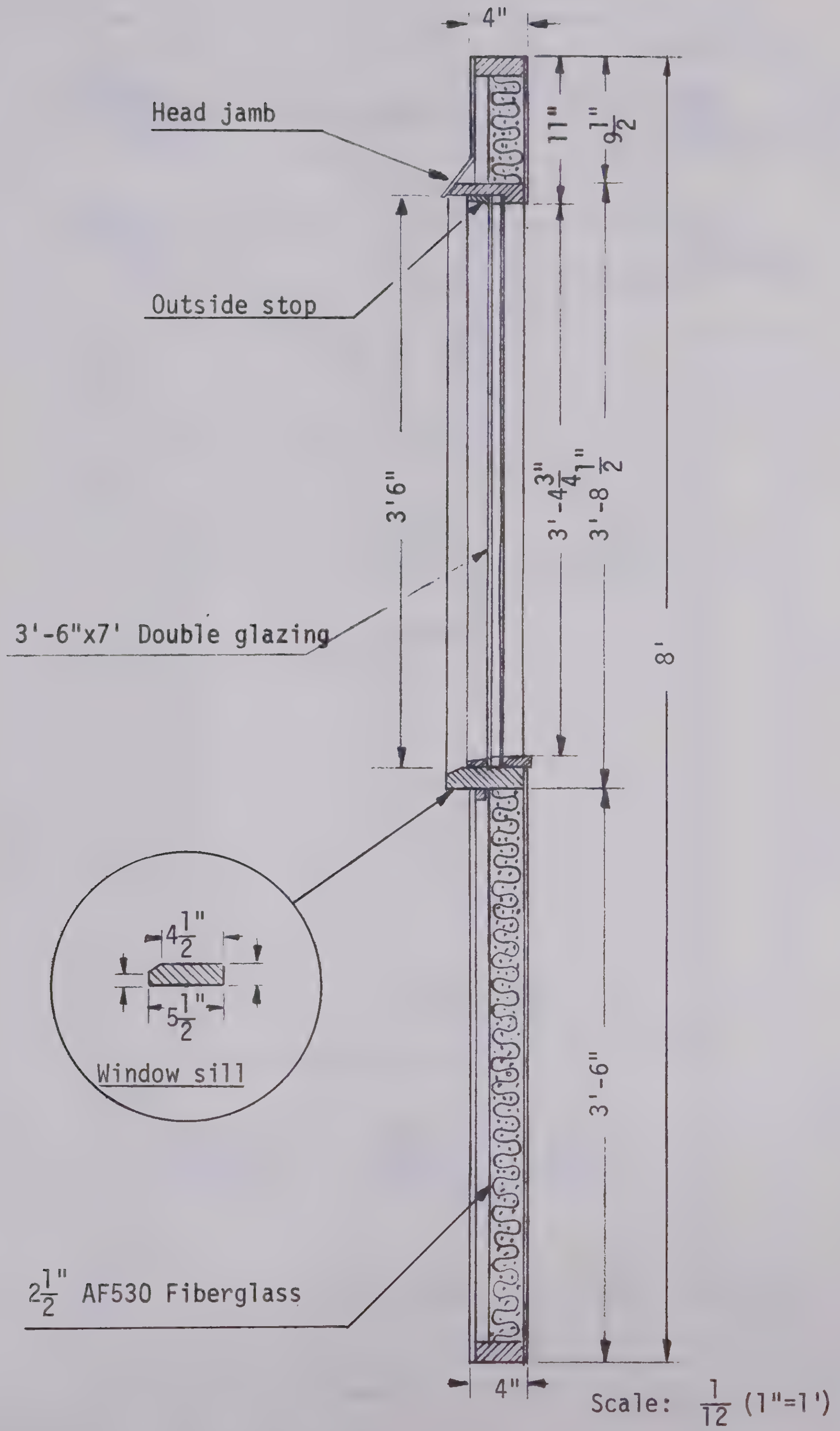


Figure 3.13 Section "G-G" of the window panel "L"

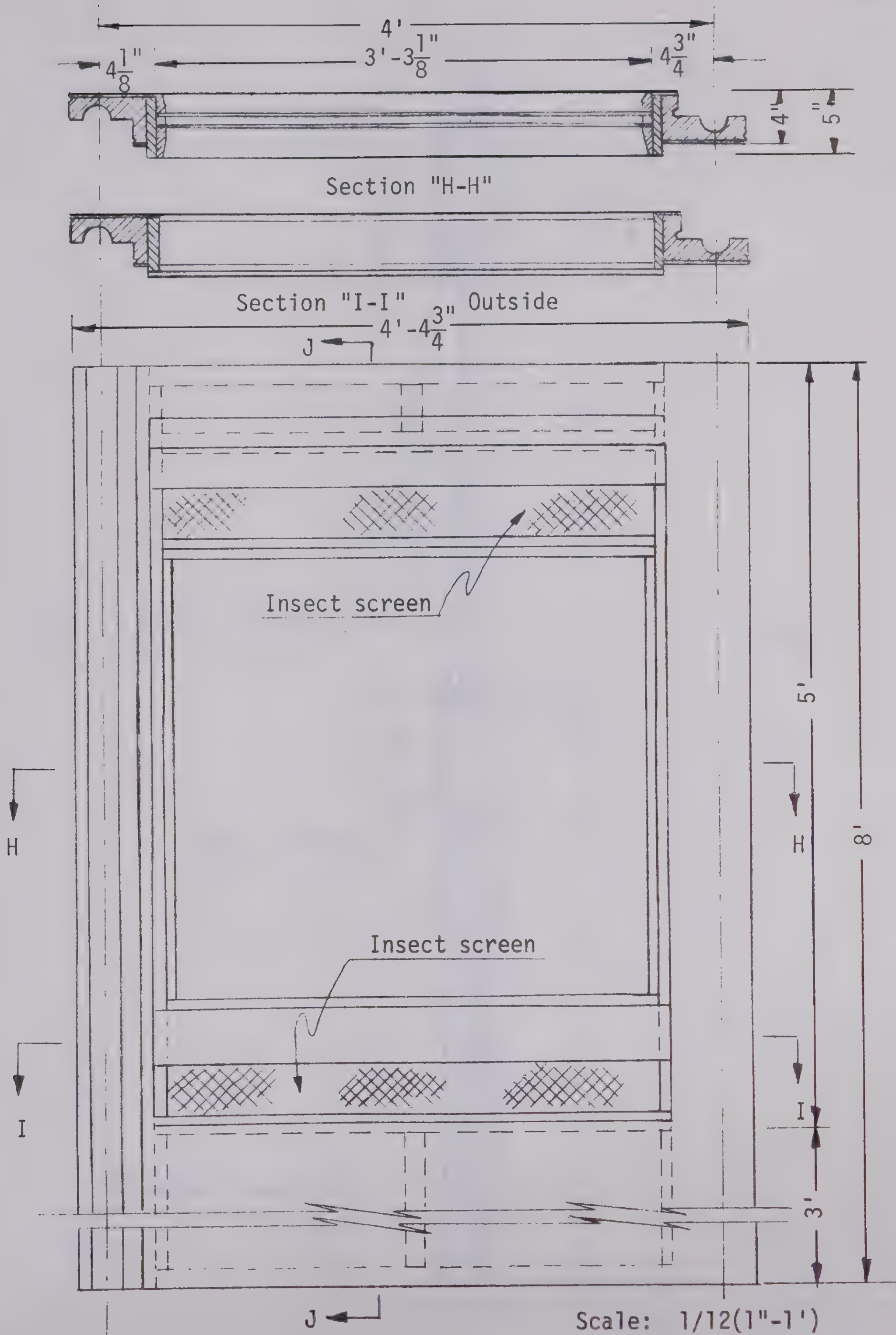


Figure 3.14 The window panel "M"

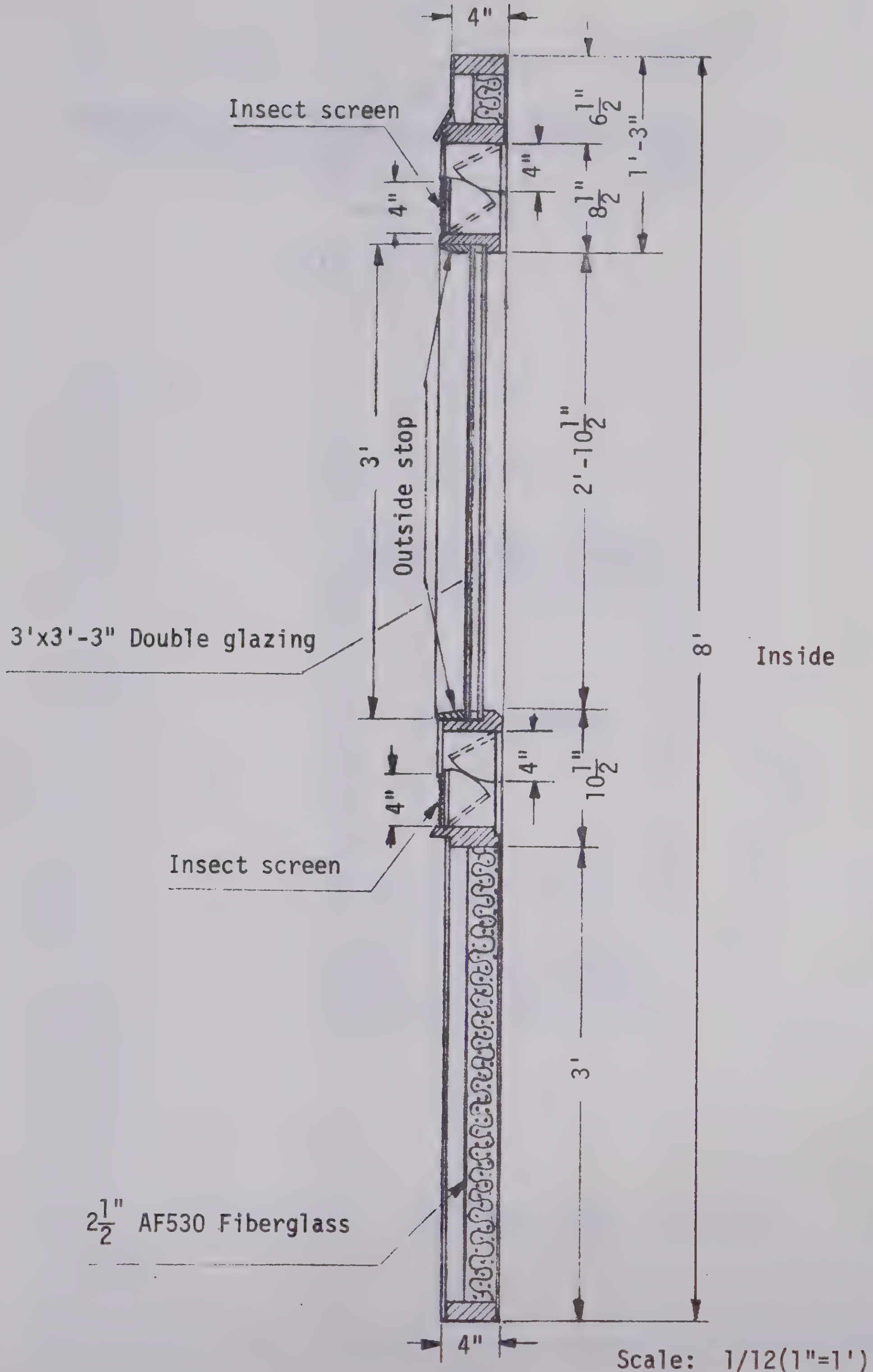


Figure 3.15 Section "J-J" of the Window panel "M"

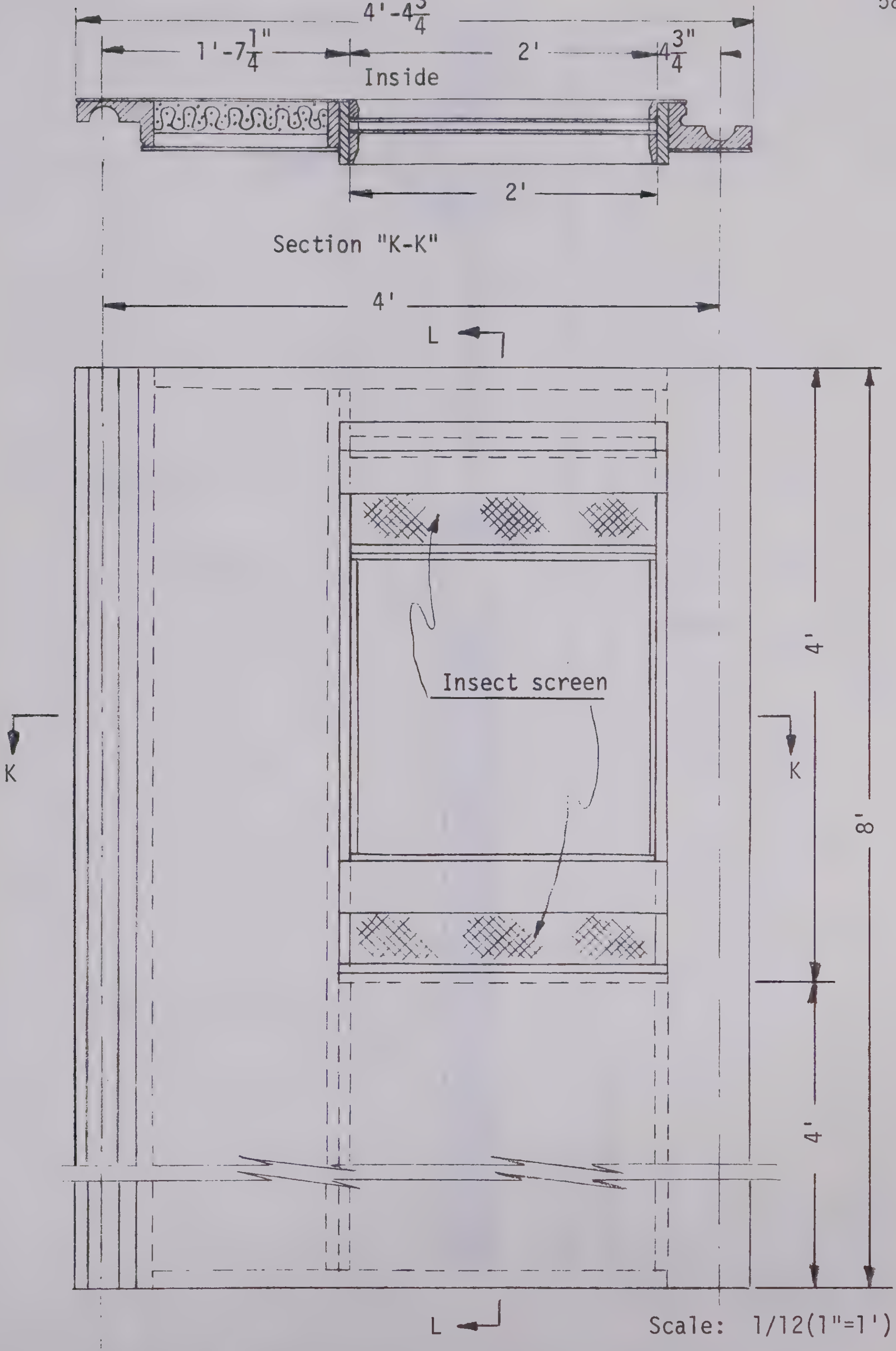
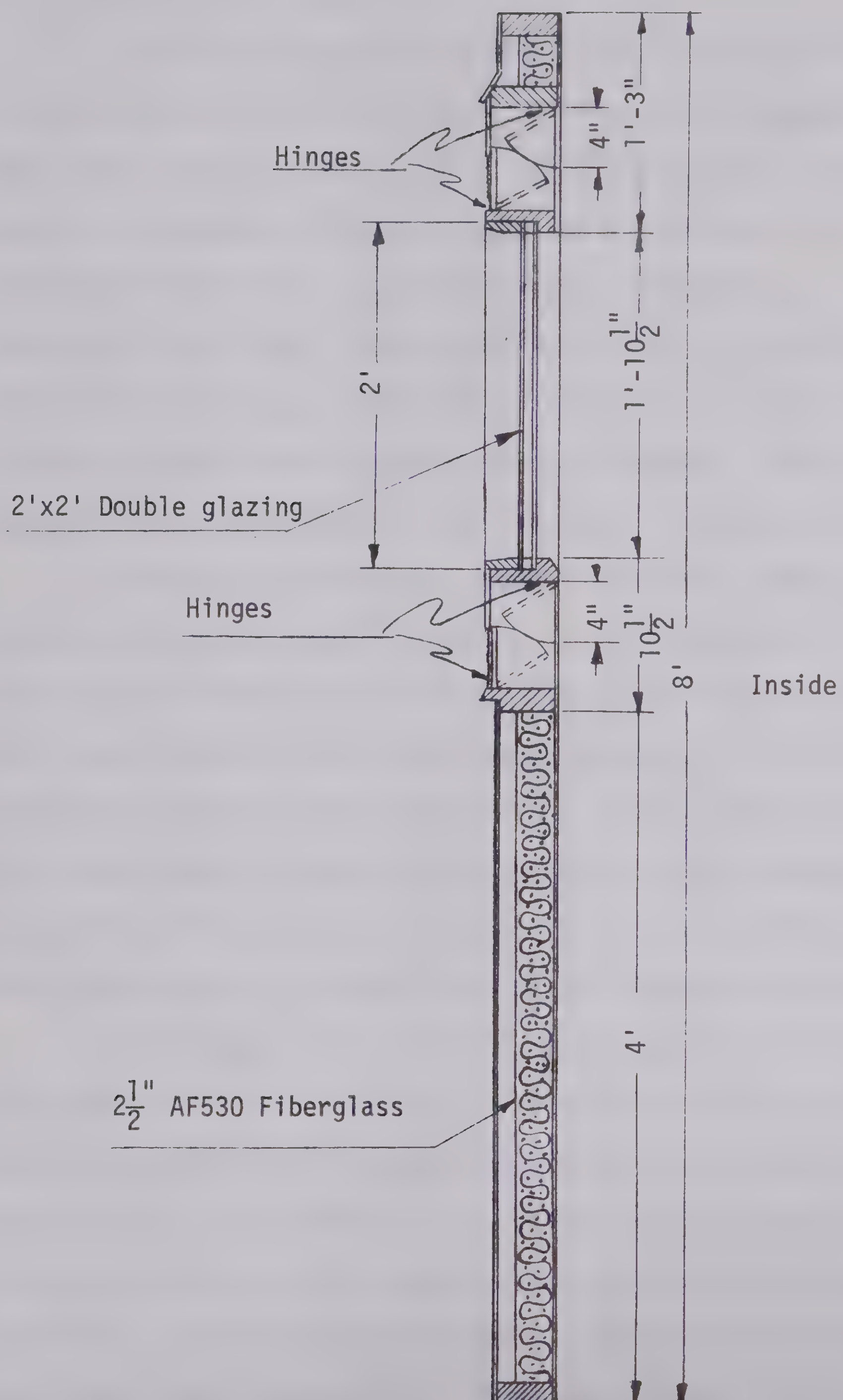


Figure 3.16 The window panel "S"



Scale: 1/12(1"=1')

Figure 3.17 Section "L-L" of the window panel "S"

3.1.4 Interior Wall Panels

Within the home complete flexibility to move partitions as desired was strived for in the design. This allows conversion of the single-family dwelling from a two to three bedroom or a three bedroom to a two bedroom with the addition of a half-bath, etc. To rearrange the floor plan to meet the changing requirements of the tenant, the chosen interior wall panel was selected for its flexibility and simplicity of handling, removal and reinstallation. Good grouping of rooms into the three functional areas of working, sleeping and living also were considered for the functional interior wall panels.

The chosen interior wall panels are almost identical to the exterior wall panels except for insulation and outside skin. The use of the same end studs in the exterior wall panel, the door panel, the window panel and the interior wall panel allows for flexibility in the manufacture and rearrangement of the floor plan. Both surfaces of the interior panel will usually be finished with the same material. The readily finished interior wall panels will be installed with the same locking mechanism which is used in the exterior wall panels.

The standard, four feet wide and eight feet high interior wall panel is shown in Figure 3.18. It would be ideal to use only one size of panel but it is almost impossible to gain the flexibility desired in floor plans with only one standard size of panel. Figures 3.19, 3.20 and 3.21 show the details of a two feet ten inch interior wall panel, a two feet six inch interior wall panel and one foot five inch end wall panel respectively. These wall panels have the same sectional view as the four foot wide panel. The interior door panel is shown in Figure 3.22, it is also four feet in width and eight feet

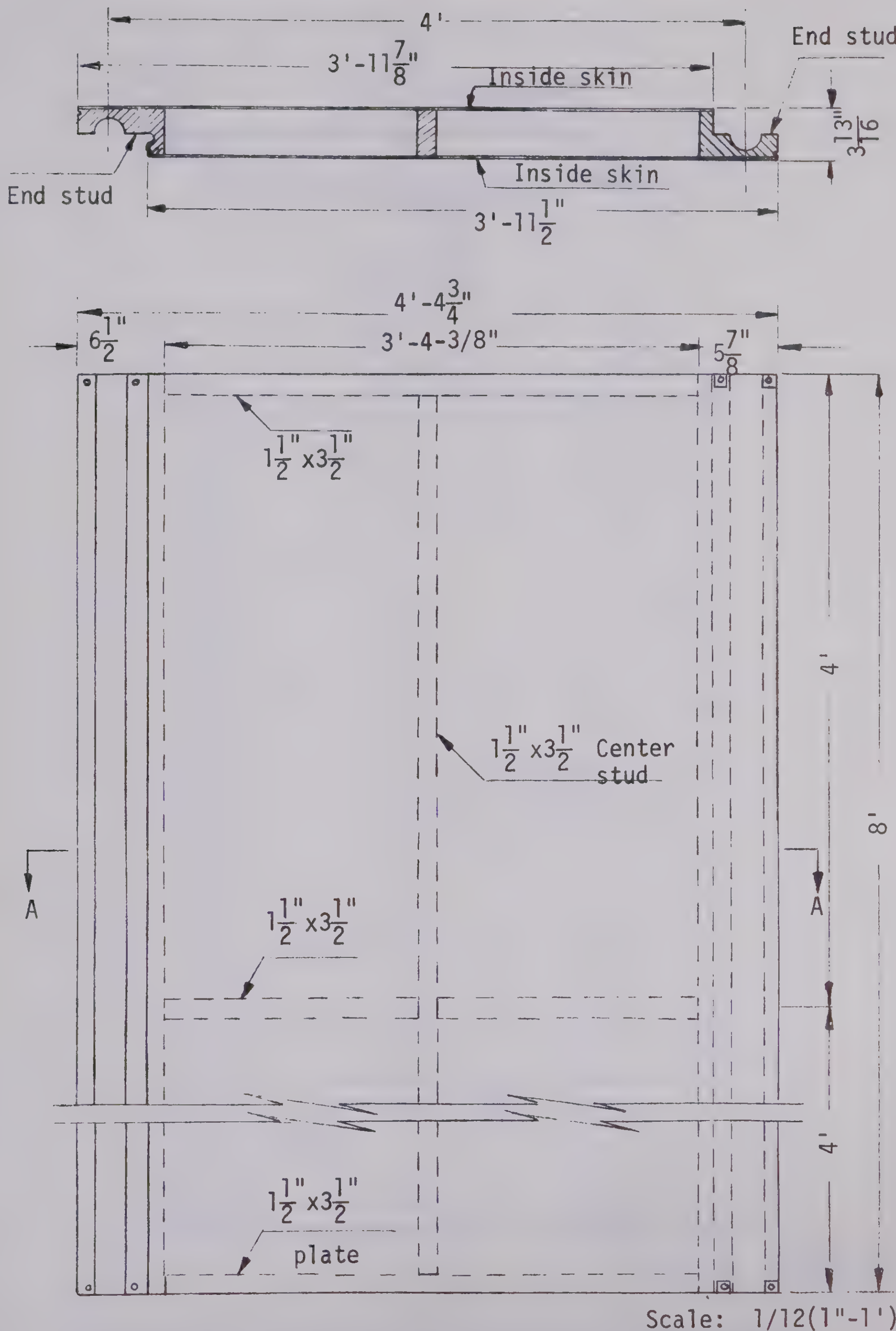
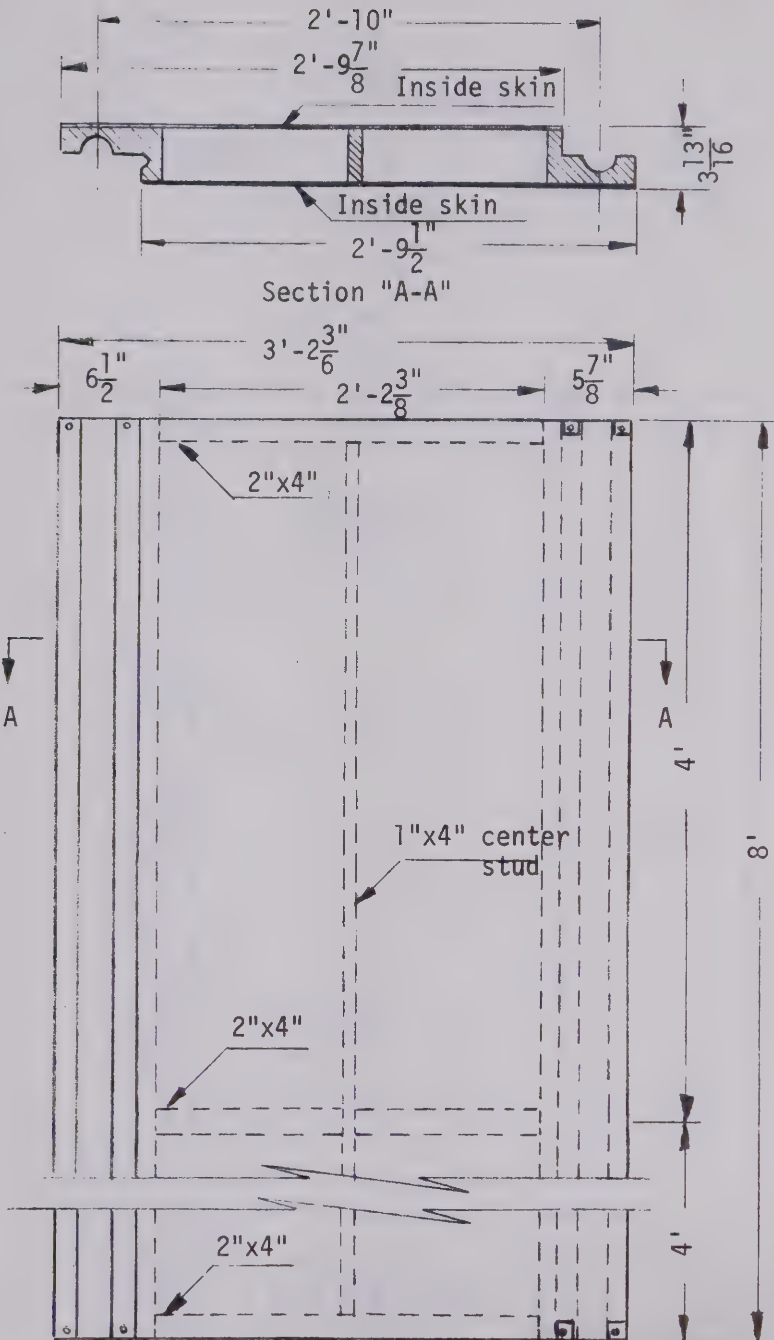
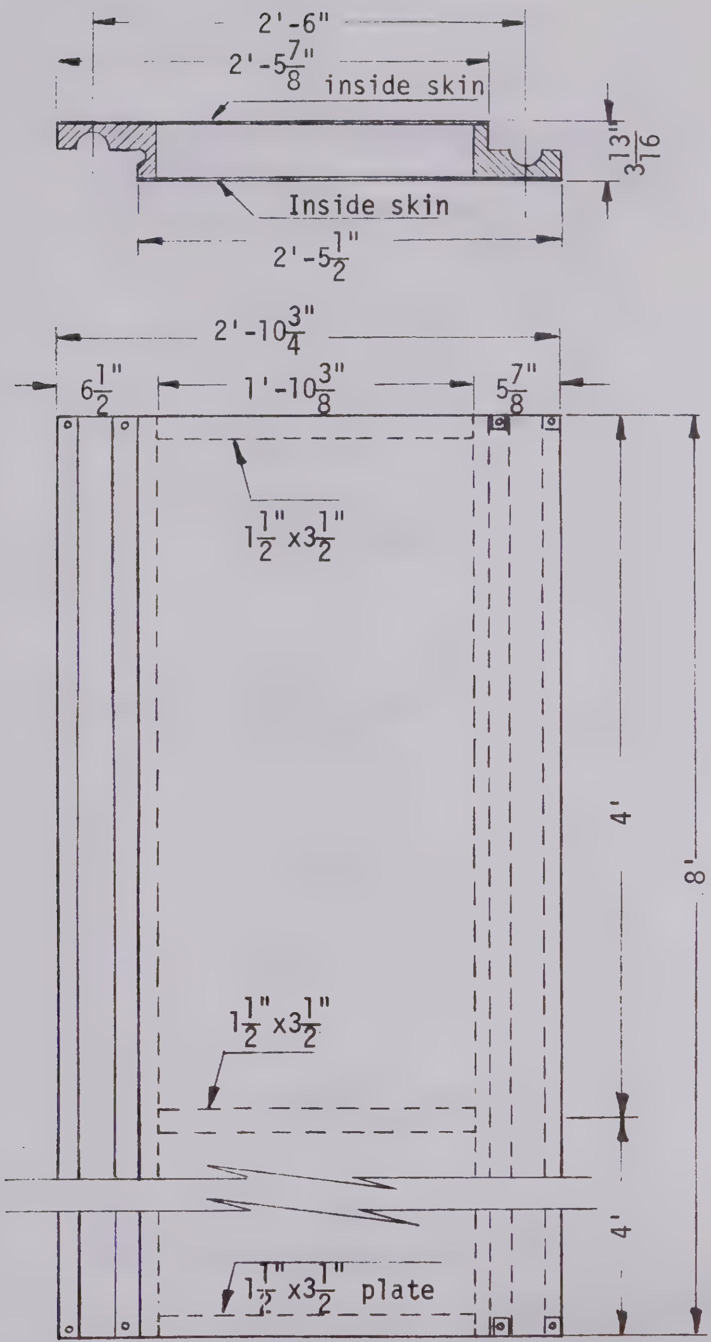


Figure 3.18 The four foot interior wall panel



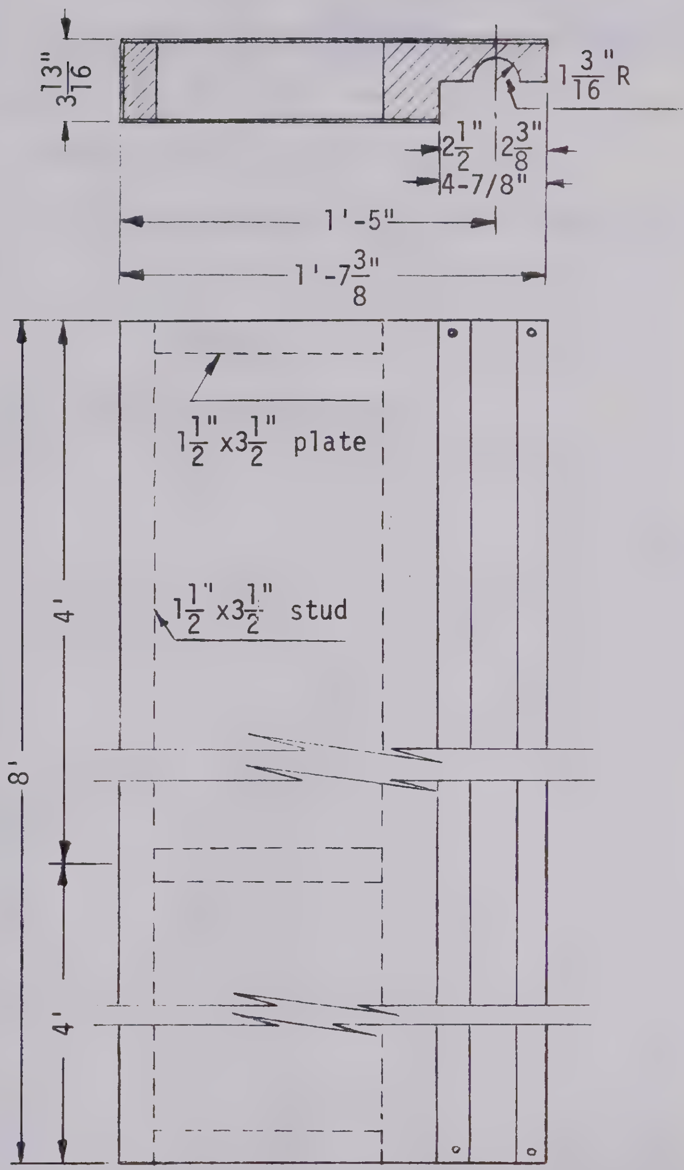
Scale: 1/12(1"-1')

Figure 3.19 The two feet ten inch interior wall panel



Scale: 1/12(1"=1')

Figure 3.20 The two feet six inch interior wall panel



Scale: 1/8(1/8"-1")

Figure 3.21 The one foot five inch interior end wall panel

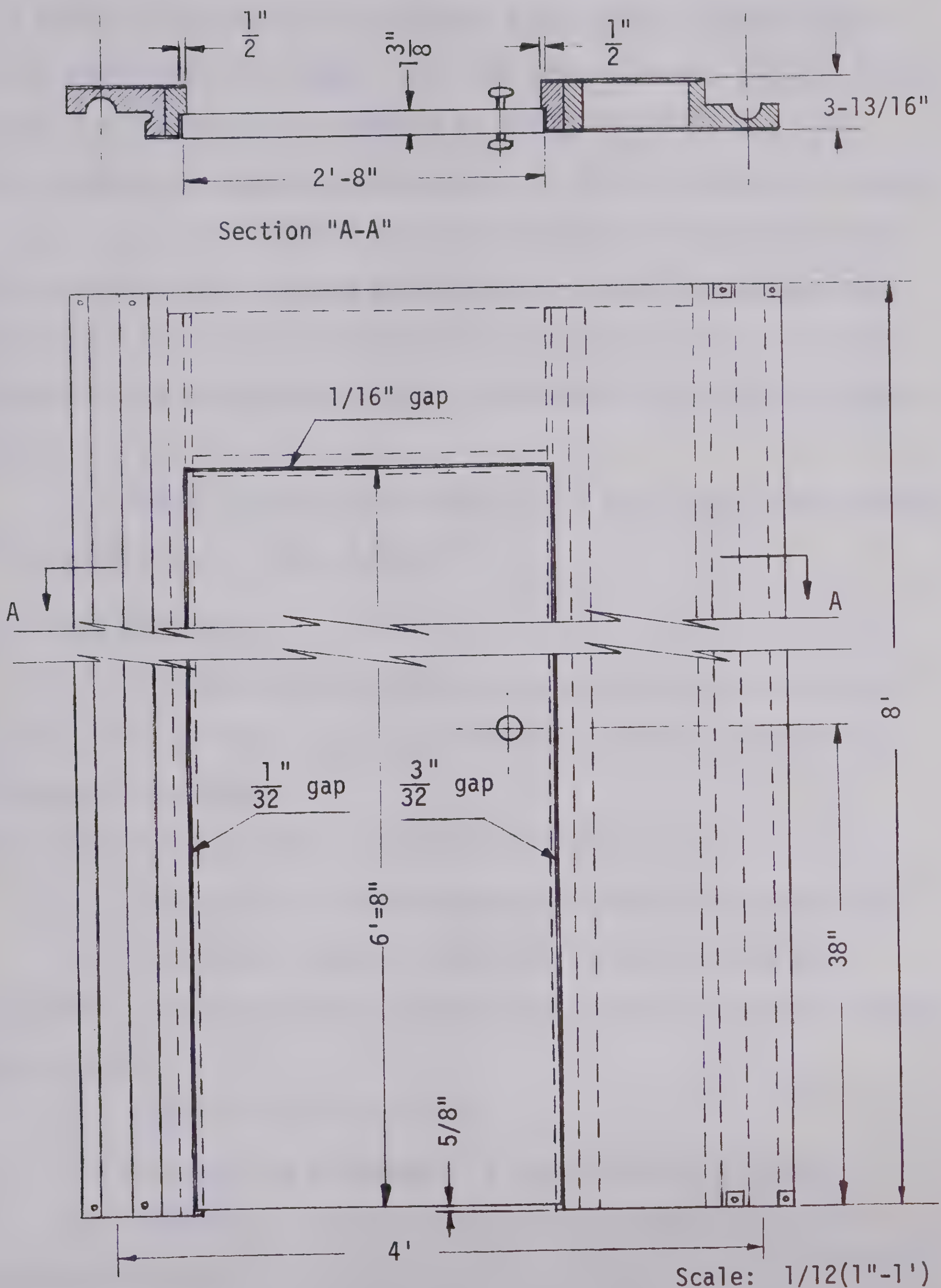


Figure 3.22 The interior door panel

in height. The door size is two feet eight inches in width and six feet eight inches in height. The interior wall panels and door panels will give the flexibility desired to the various floor plans, rearrangements and possible extensions of the FLEXI-GROW housing system.

It is recommended that each component of the interior wall panel be made from the same material which is used for the exterior wall panel except for the outside skin, because the size of each component of the interior wall panel is identical to that of the exterior wall.

A four feet by eight feet interior wall panel weighs approximately 103 pounds. (See Appendix E).

3.2 The Roof System

The roof system was designed to give complete flexibility of the enclosed floor area and possible expansion to accommodate the desires of the tenant.

Specification Requirements of the Desired Roof System

The chosen roof system should be optimal with regard to:

1. Structural soundness, aesthetical attractiveness and economical acceptance to the customer with a minimum of final finishing on the site;

2. Changes in the floor plan;

3. An open-beam structure or a closed ceiling structure;

4. Flexibility in manufacturing from a large number of building materials;

5. Trouble free tolerances and ruggedness to withstand shipment over fairly large distances; and

6. Ease of handling and assembling by inexperienced personnel on the building site.

The Chosen Design

Over the years, builders in Canada have developed factory fabricated building components such as, wall panels, windows and floors, however, little progress has been made in developing complete components for the roof.

The roof offers a large unbroken rectangular area that should be easily subdivided into simple repeated components, but the common arrangement of a sloping roof and a horizontal ceiling tends to defeat a roof panel system. However, the Research Committee of the National House Builders' Association recently used a unique method of including a sloped roof and a flat ceiling in one panel of stressed skin plywood construction in the Mark III experimental project built near Ottawa [20]. This panel system with minor revisions was adopted to the FLEXI-GROW housing system. The detailed design of this system is described in the following sections.

3.2.1 The Roof Panels

The stressed skin panel has light, strong sheet materials as structural skins. The panel acts as a group of I-beams and the skins act as flanges in bending. A sample panel which was tested by the National House Builders' Association, having only a four inch thickness with 3/8 inch plywood skins and one by four inch webs, is sufficient to span 12 feet under a snow load of 50 pounds per square

foot with a deflection of 1/240 of the span [20].

The chosen roof panels are designed for the basic floor plan of 960 square feet which is shown in Figure 2.6. The extension of roof panels will be discussed in section 3.5.

The detailed design of a standard roof panel is shown in Figure 3.23, it is four feet in width, 13 feet 7-1/2 inches in length and 4-1/8 inches in thickenss. The outside skin chosen is 3/8 inch plywood. One-quarter inch plywood is used for the inside skin, and one inch by four inch webs are used every foot. To reinforce the 13 feet 7-1/2 inch length roof panel, two by four inch blocking and 3/8 inch by six inch splice plates are used at the connection point.

Figure 3.24 and Figure 3.25 show a center roof panel and an end roof panel respectively. The center roof panel is two feet in width, and the sectional view of the panel length is the same as the standard roof panel. The end roof panel is identical to the standard roof panel except for the one end shape which is matched with the rafter size.

The arrangement of roof panels for the basic floor plan of 960 square feet, is shown in Figure 3.26. Two pieces of center roof panel, 16 standard roof panels and four pieces of end roof panel are required for one home with a 40 feet by 24 feet floor plan. This roof allows one foot of eave and it has a 5/13 slope using a conventional gable roof style (see Figure 3.27). The section view "C-C" and "D-D" show how two roof panels are connected to each other on the building site. Rafters will be installed when the load bearing structures are installed, then each roof panel can be inserted between the rafters.

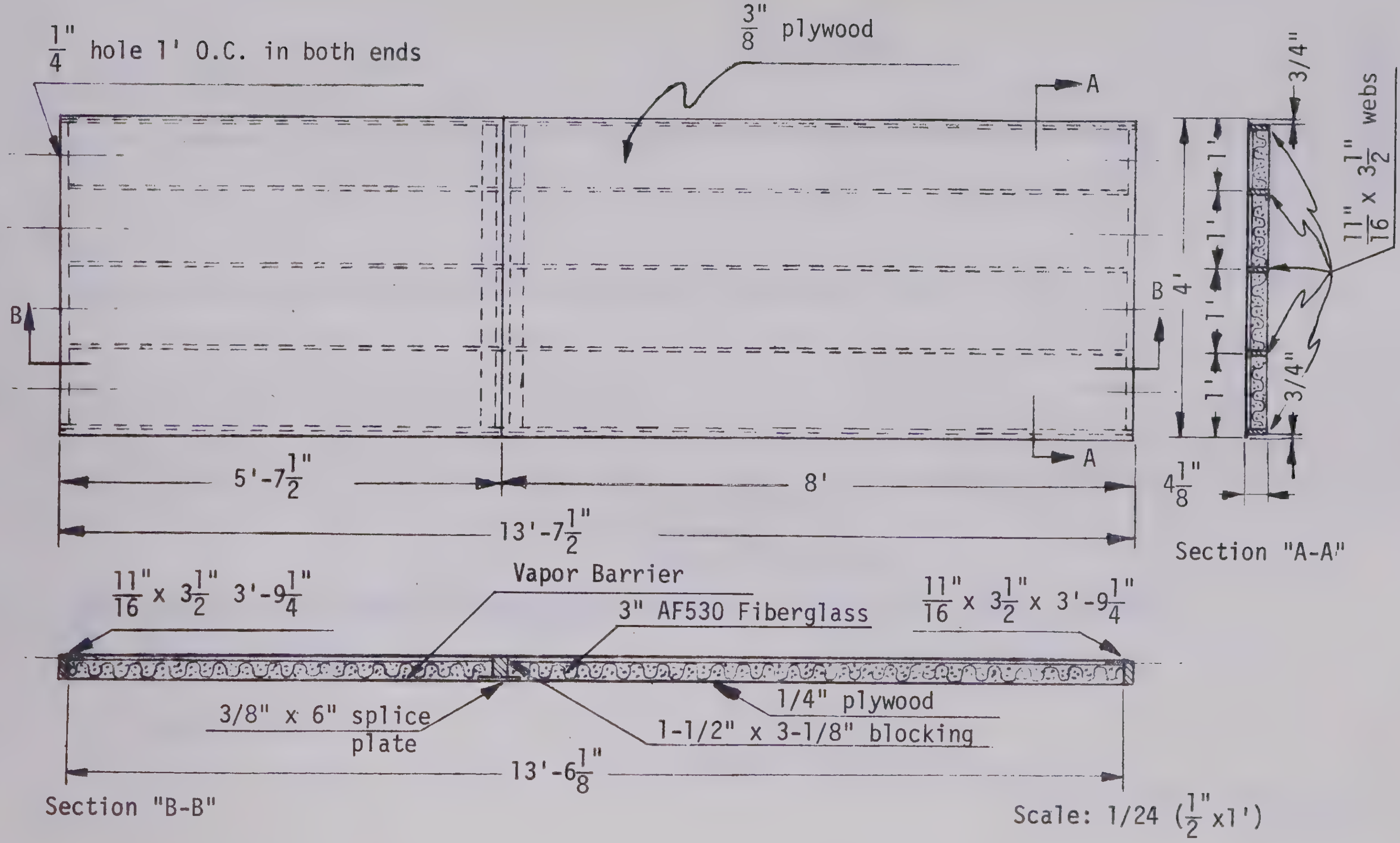
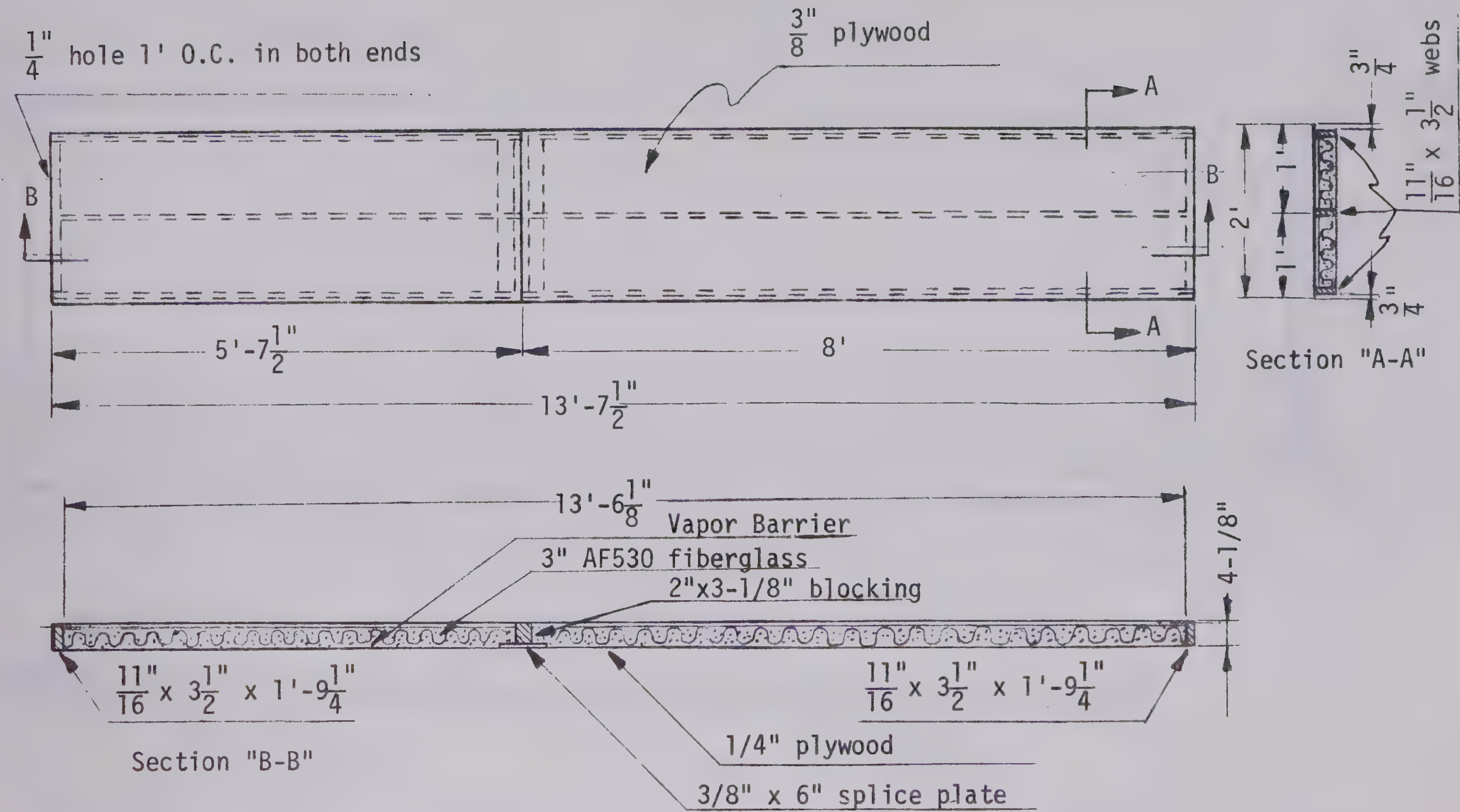


Figure 3.23 The Standard Roof Panel



Scale: 1/24 (1/2"=1')

Figure 3.24 The Center roof panel

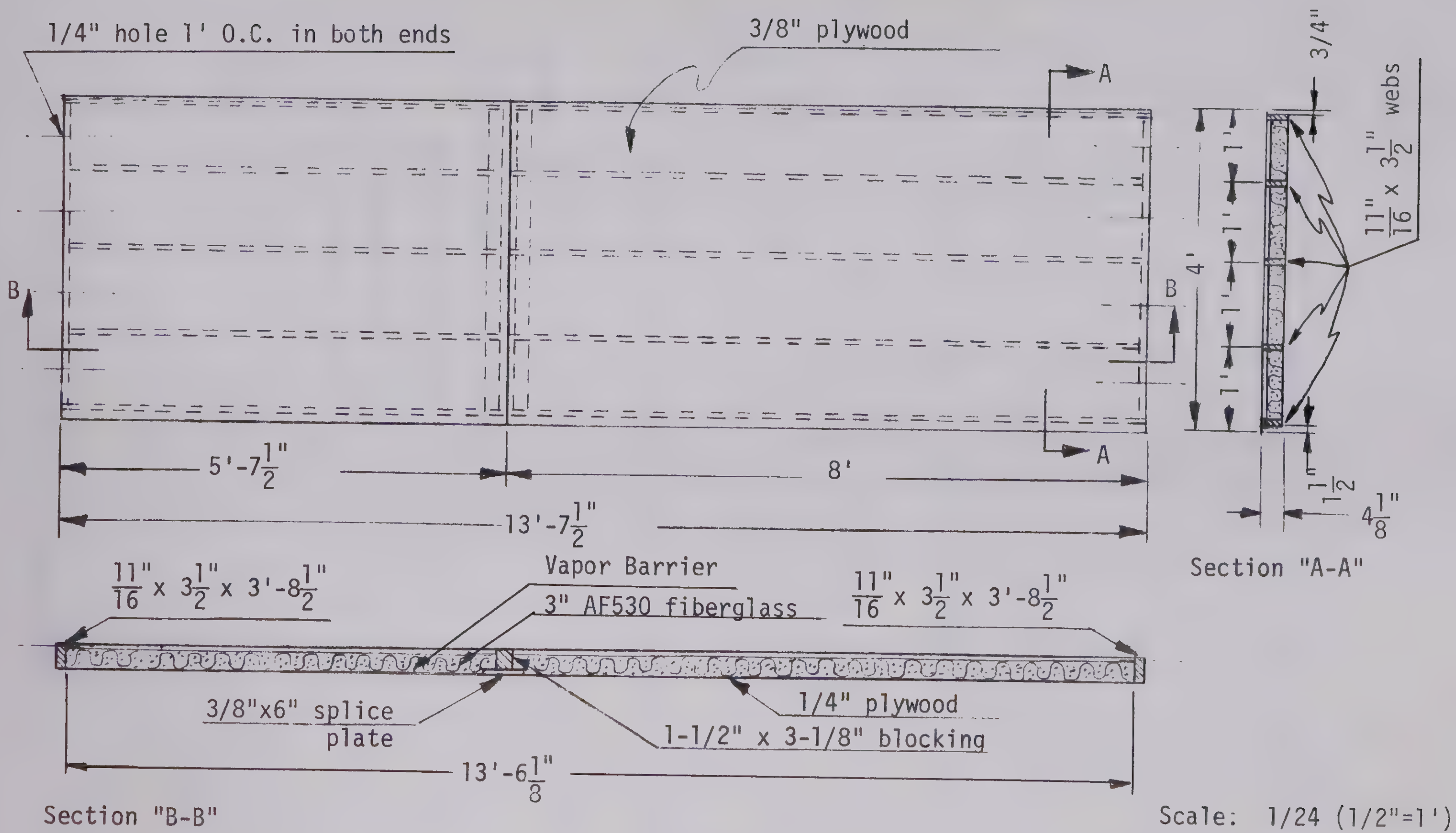
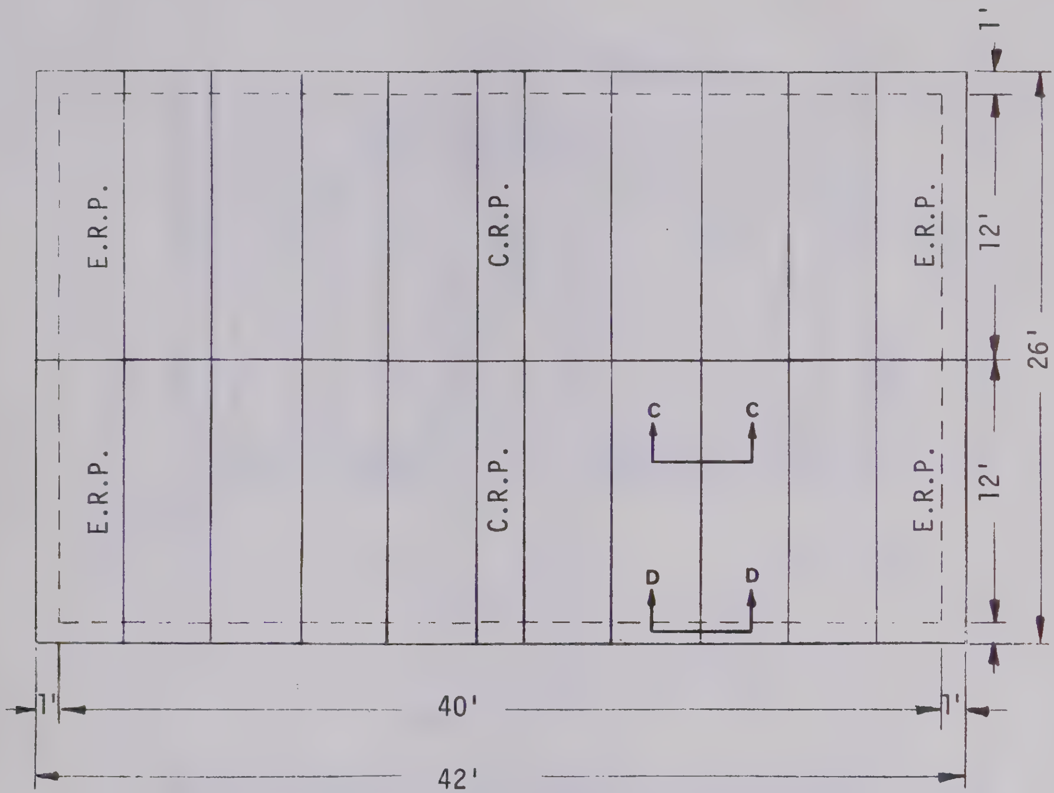


Figure 3.25 The end roof panel



Floor: 40'x24'

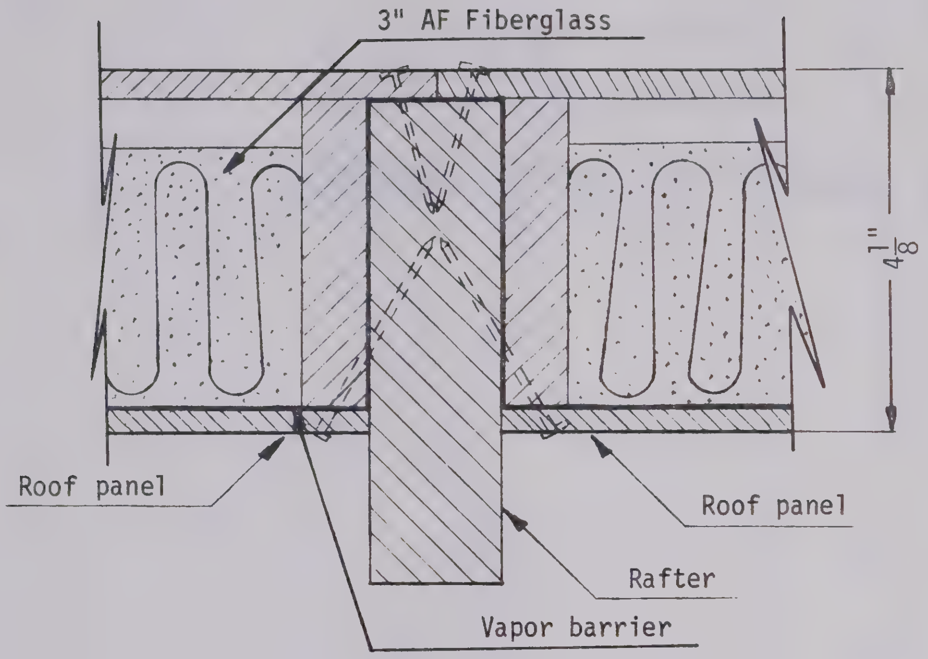
Required number of roof panels

2' center roof panel	2
4' standard roof panel	16
4' end roof panel	4

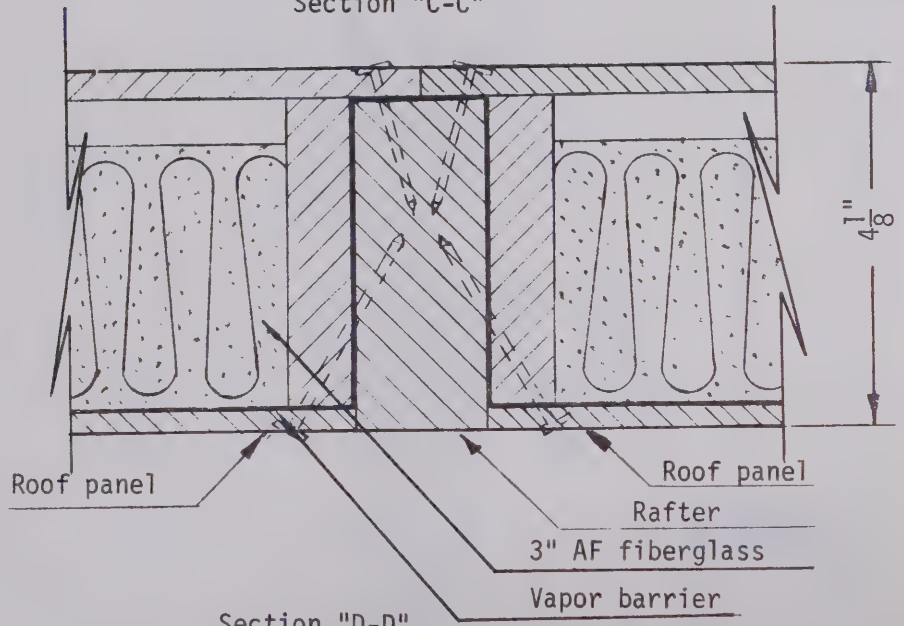
Total roof area 42' x (13.75 x 2) = 1155 ft^2

Scale: $1/96(\frac{1}{8}"=1')$

Figure 3.26 The roof panel system



Section "C-C"



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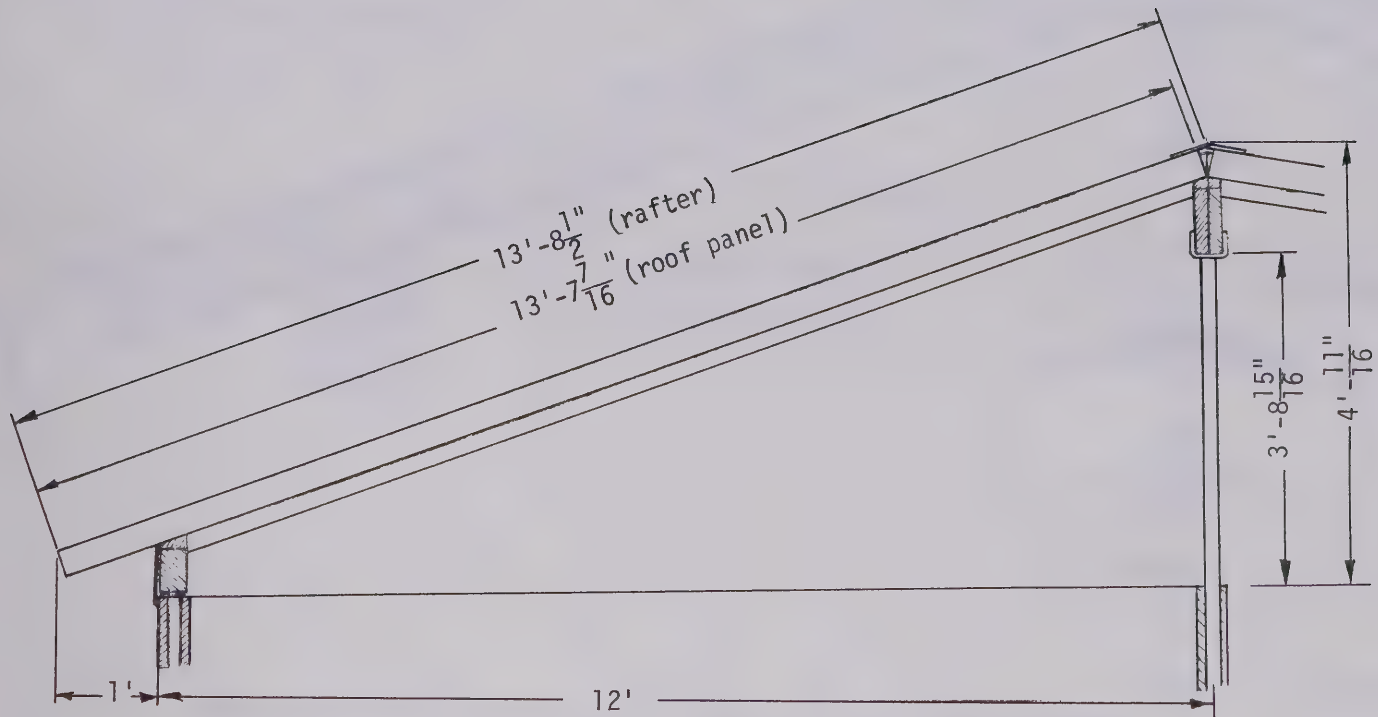


Scale: 1/24 (1"=2')

Figure 3.27 A cross section of the roof

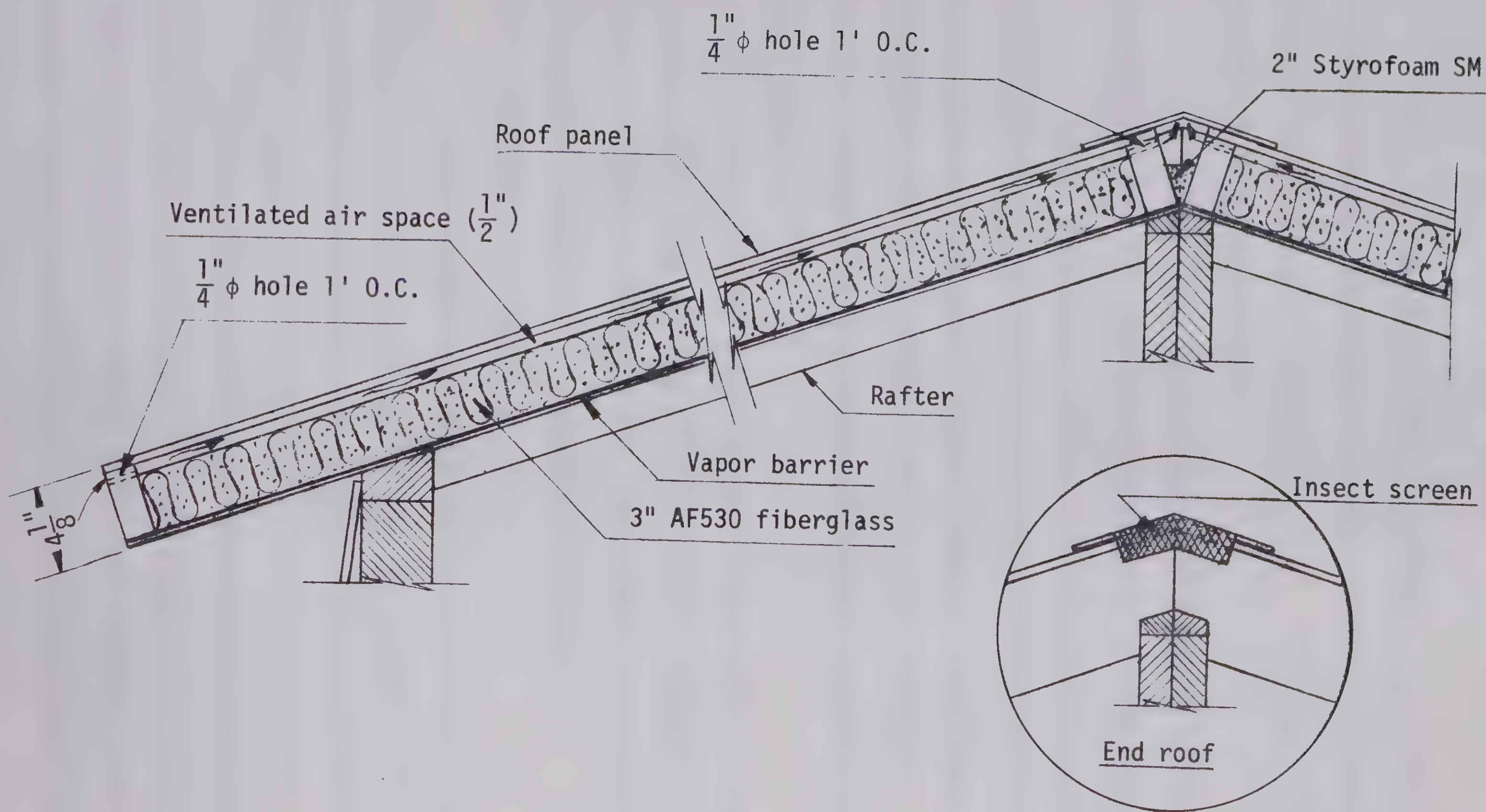


Figure 3.28 Air ventilation and vapor barrier in the roof panel

The insulation is readily assembled in the roof panel during manufacture, therefore, it is not necessary to install insulation above the ceiling on the building site. The chosen insulation material is AF530 fiberglass.

A standard roof panel weighs approximately 222 pounds. (See Appendix E). It will require mechanical equipment to handle.

Figure 3.28 shows how the air ventilation would be accomplished within the stressed skin roof panel and where the vapor barrier should be installed. One-half inch air space between the outside skin and the insulation will allow air ventilation. The main air passage is located longitudinally just beneath the summit of the roof.

The chosen roof panel system can be used for an open-beam structure or a closed ceiling structure. This system will not cause any change in the floor plan. The inside surface of the roof panel may be finished in the factory, if desired.

3.2.2 Roof Weather Proofing

The FLEXI-GROW housing system requires a roof coating system in which the roof panels are coated by a roofing material in the factory and finished on the site by applying the same roofing material or a sealant on the junction line of the roof panels.

In the present market there are several roof coating materials available, which have been developed for concrete or asphalt roof decks of multi-story buildings. However, roof coating materials for the wooden roof of a single-detached home is difficult

to find for, at least the following reasons:

1. Shingled and tiled roofs have been used traditionally in Canada.

2. Shingled and tiled roofs seldom leak despite the many openings through them because rain penetration is prevented by overlapping the shingles.

3. It is easy to handle small pieces of shingle on the sloped roof after the conventional roof structure is installed on the site.

4. It is hard to apply a roof coating material on the conventional gable roof on the site, unless it is a solid material.

In spite of several advantages mentioned above for the shingled or tiled roofs, there are also some disadvantages which are listed below:

1. Shingled or tiled roofs are heavy, for example, asbestos shingles weigh about 300 lbs. to 500 lbs. per 100 ft^2 coverage and tiled roofs weigh 750 to 1200 lbs per 100 ft^2 coverage. These factors result in additional transportation and installation costs.

2. Overlapping the shingles or tiles also requires more man-hours.

3. Shingled or tiled roofs cannot be readily assembled in the factory.

The "Scotch-Clad" deck coating materials [14] manufactured by the Minnesota Mining and Manufacturing of Canada Ltd. in London, Ontario was selected as the most feasible material in the present market for the roof coating system of the FLEXI-GROW housing system.

The specifications of the chosen material are listed below:

1. Synthetic elastomeric material possessing extremely good elongation and recovery properties, stays tough yet flexible to maintain a waterproof seal.

2. Bonds aggressively to properly prepared surface of concrete, masonry, stone, asphalt, wood and other cellulosic materials.

3. No moisture entrapment is included.

4. Very rugged and resistant to abrasion --- even withstands studded tires and chains on vehicular decks.

5. Maintains its flexibility, adhesion and elastomeric properties under severe weather exposure with a temperature performance range of -40°F to +160°F.

6. Effectively resists oils, gasoline, most acids and alkalies.

7. Any necessary repairs to damaged areas are accomplished very easily and quickly.

8. Non-skid surface is easily accomplished by mixing non-skid grit in with top coat before applying.

9. Color selection is available in 11 attractive colors.

10. Simple 2-coat system contributes to substantial savings economically, and the total thickness of the coating is only around 1/16 of an inch.

3.2.3 The Ceiling

Either a horizontal ceiling or an open-beam structure may be used.

As previously mentioned no insulation is required over the ceiling in the FLEXI-GROW housing system, therefore, a light and good

looking ceiling board should be acceptable where a horizontal ceiling is required. A simple "T" shape ceiling joist can be easily installed on the site and the light ceiling board installed. (See Figure 3.35)

The ceiling joist is connected by screws to the center wall holding plate and the upper beam of the exterior wall. The distance from one ceiling joist to another (center to center) is two feet.

3.3 The Floor System

The floor system has been designed to accommodate the chosen wall and roof systems for the FLEXI-GROW housing system:

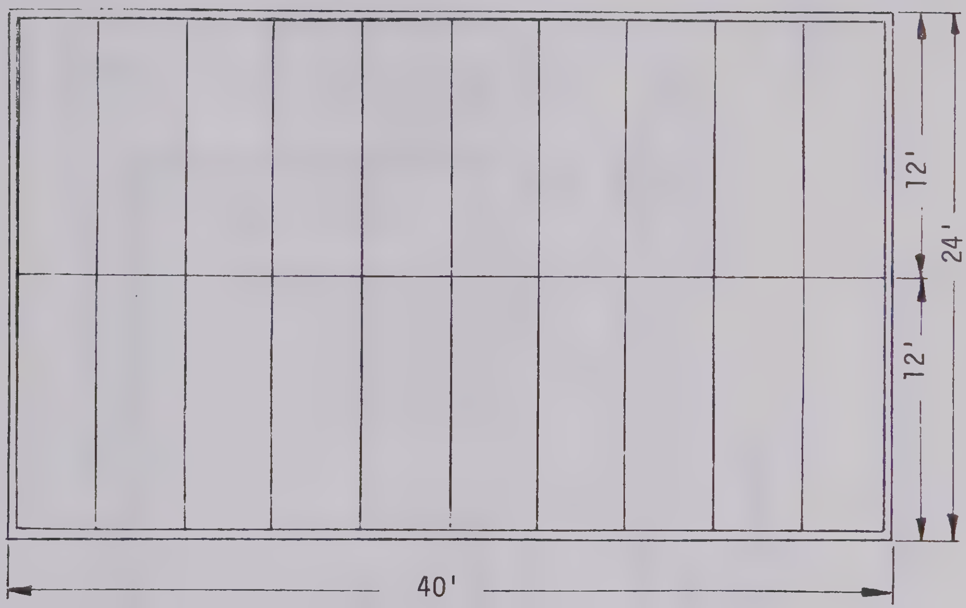
Specification Requirements of the Desired Floor System

The optimum floor system was selected to promote:

1. Economical and aesthetical acceptance to the tenant;
2. A minimum of final finishing on the site;
3. Structural soundness to support possible loads;
4. The minimum disturbance to the change of floor plan and easy installation and extension;
5. Flexibility in manufacturing from a large number of building materials;
6. Trouble free tolerances and ruggedness to withstand shipment over fairly large distances; and
7. Ease of handling and assembling by inexperienced personnel on the building site.

The Chosen Design

The floor panel system in which the floor panels are manufactured in the factory and assembled on the site, was selected as the



Scale: 1/96(1/8"=1')

Figure 3.29 The floor panel system

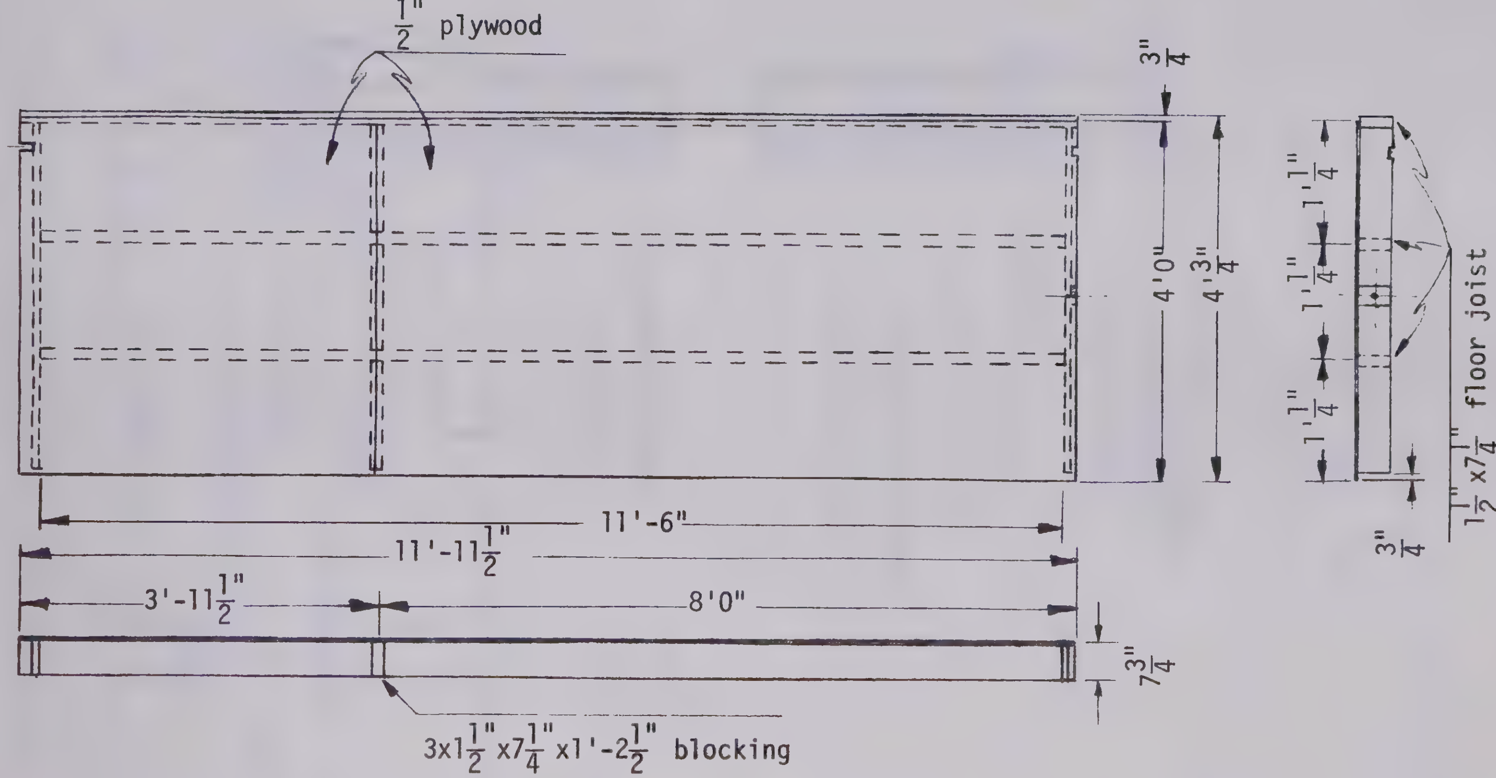


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Figure 3.30 The standard floor panel

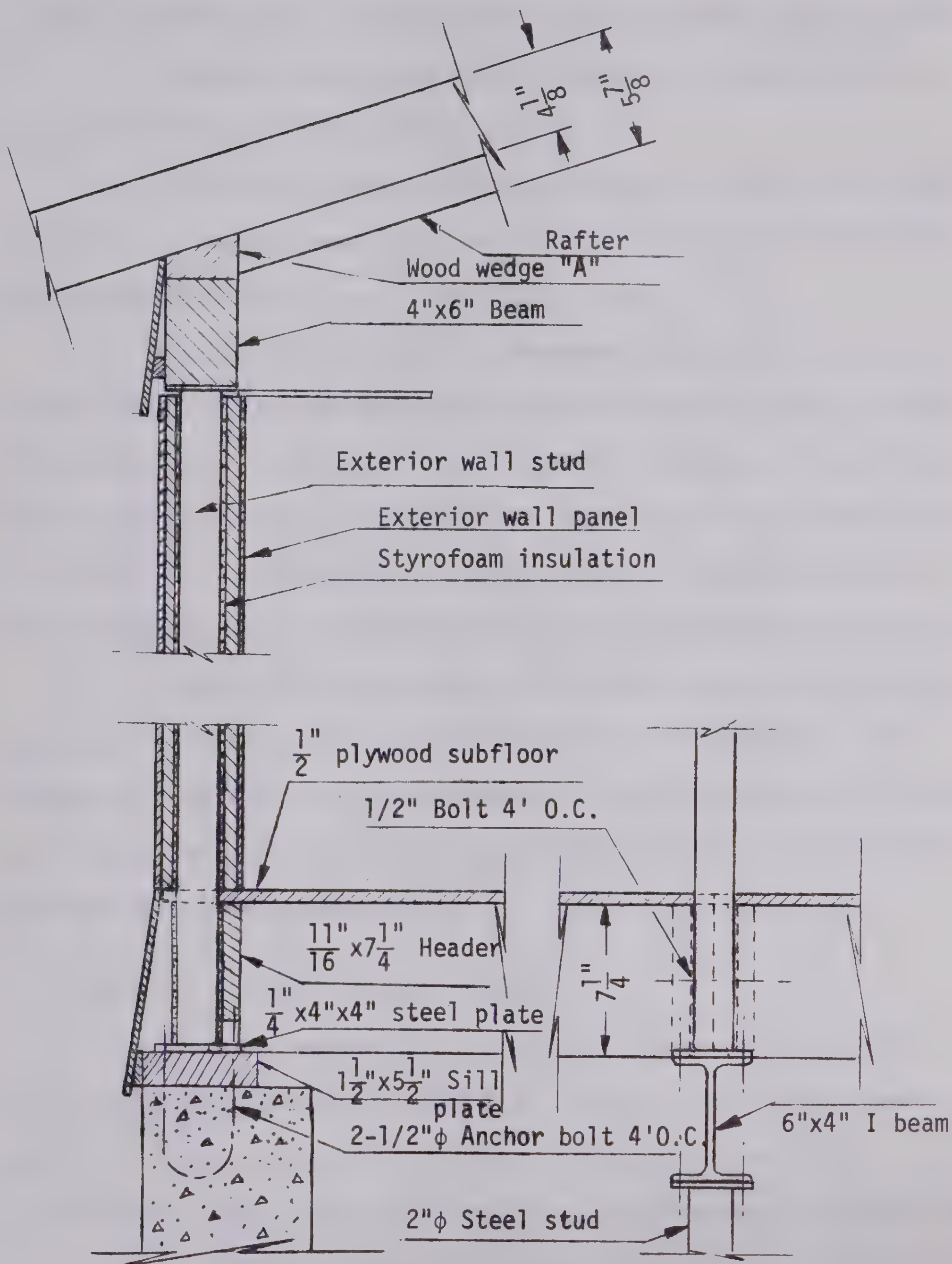


Figure 3.31 Installation details of a floor panel

optimal system to meet the function of the FLEXI-GROW housing system.

The total floor area can be divided into twenty sections by one center and nine transverse lines.

The size of each section is four feet in width and 12 feet in length. Twenty pieces of these sections will be required for the 960 square feet floor plan. (See Figure 3.29).

The detailed design of a standard floor panel is shown in Figure 3.30, it is four feet three-quarter inches in width, 11 feet 11-1/2 inches in length and 7-3/4 inches in thickness. One-half inch thick plywood is used as the subfloor, two by eight inch floor joists are placed every one foot one quarter inch. To reinforce the connection points of the plywood two by eight inch blockings are used.

Figure 3.31 shows how the floor panels may be installed and connected to other housing components on the building site. It is suggested that the floor panels should be installed before the exterior wall panels are assembled. The approximate weight of a floor panel is 194 lbs. (See Appendix E).

3.4 The Load Bearing Structure System

The load bearing structure system chosen was designed to have sufficient structural capacity to meet necessary requirements, while allowing complete flexibility to change the floor plan.

Specification Requirements of the Desired Load Bearing Structure System

The chosen load bearing structure system was selected to meet the following requirements:

1. Sufficient structural capacity to safely resist all effects of loading that may be expected;

2. Minimum disturbance created by a change of floor plan;

3. Simplicity in handling and assembly;

4. Economical feasibility; and

5. Flexibility in manufacturing from a large number of building materials.

The Chosen Design

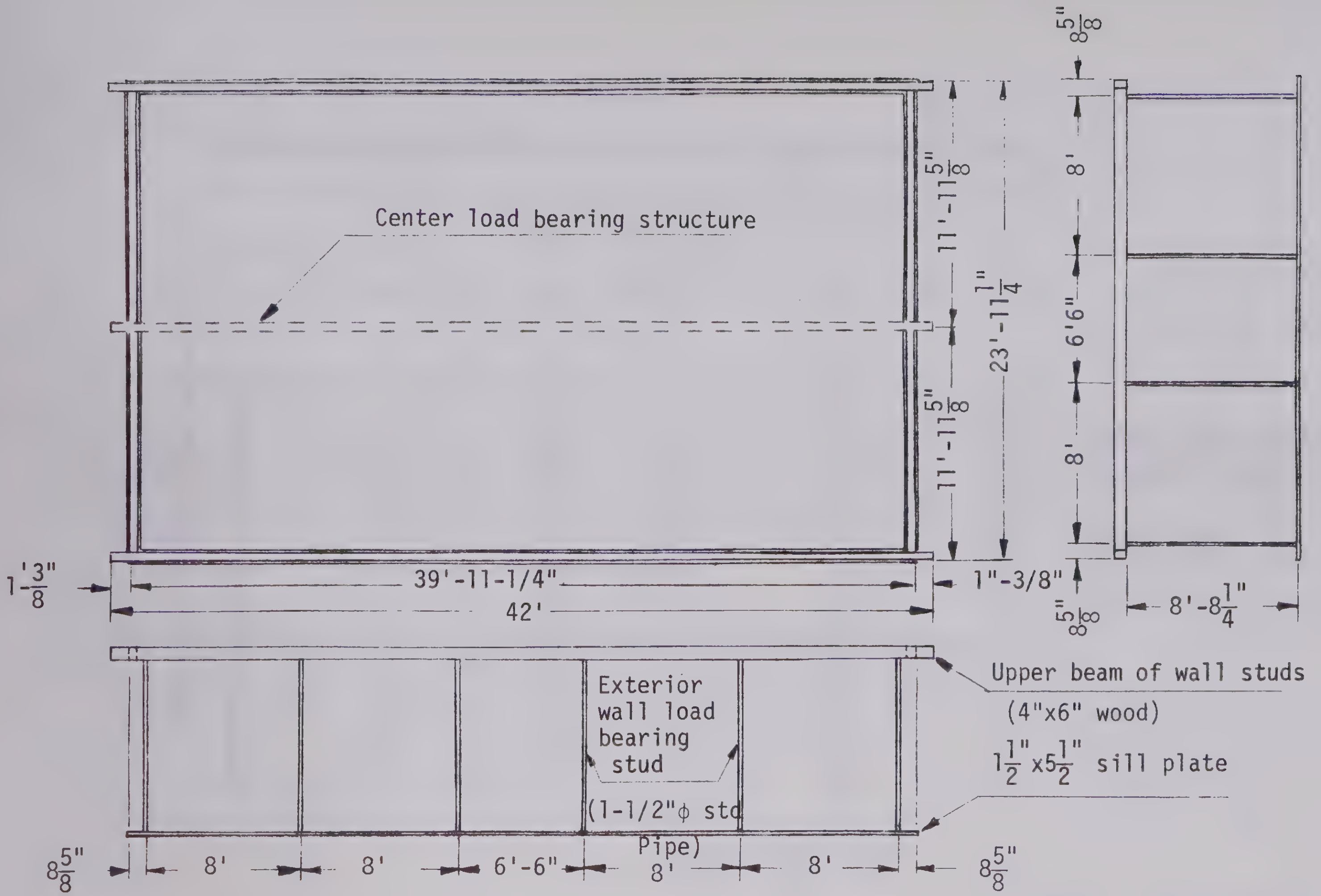
The prefabricated beam and stud system in which beams and studs are prefabricated in the factory and assembled on the site, was selected to satisfy the above requirements. The chosen detailed design is as follows.

The total load on the house is distributed through the center line and the exterior wall lines. Figure 3.32 shows the total load bearing structure which consists of a center load bearing structure and the exterior wall load bearing structure. The details of the center load bearing structure are shown in Figure 3.33.

The total roof load including the dead load, the snow load and the wind load, is carried by the center load bearing studs and the exterior wall load bearing studs, therefore, each exterior wall panel or interior wall panel is free from the vertical load.

There are several alternative materials available for structural members in the present market, however, steel and wood are selected as feasible alternative materials for their simplicity, ease of procurement, flexibility of manufacturing and handling.

Steel and wood were compared for each structural member with respect to their physical properties, required amount per home, cost and adaptability to the FLEXI-GROW housing system, then the



Scale: 1/96 (1/8"=1')

Figure 3.32 The load bearing structure

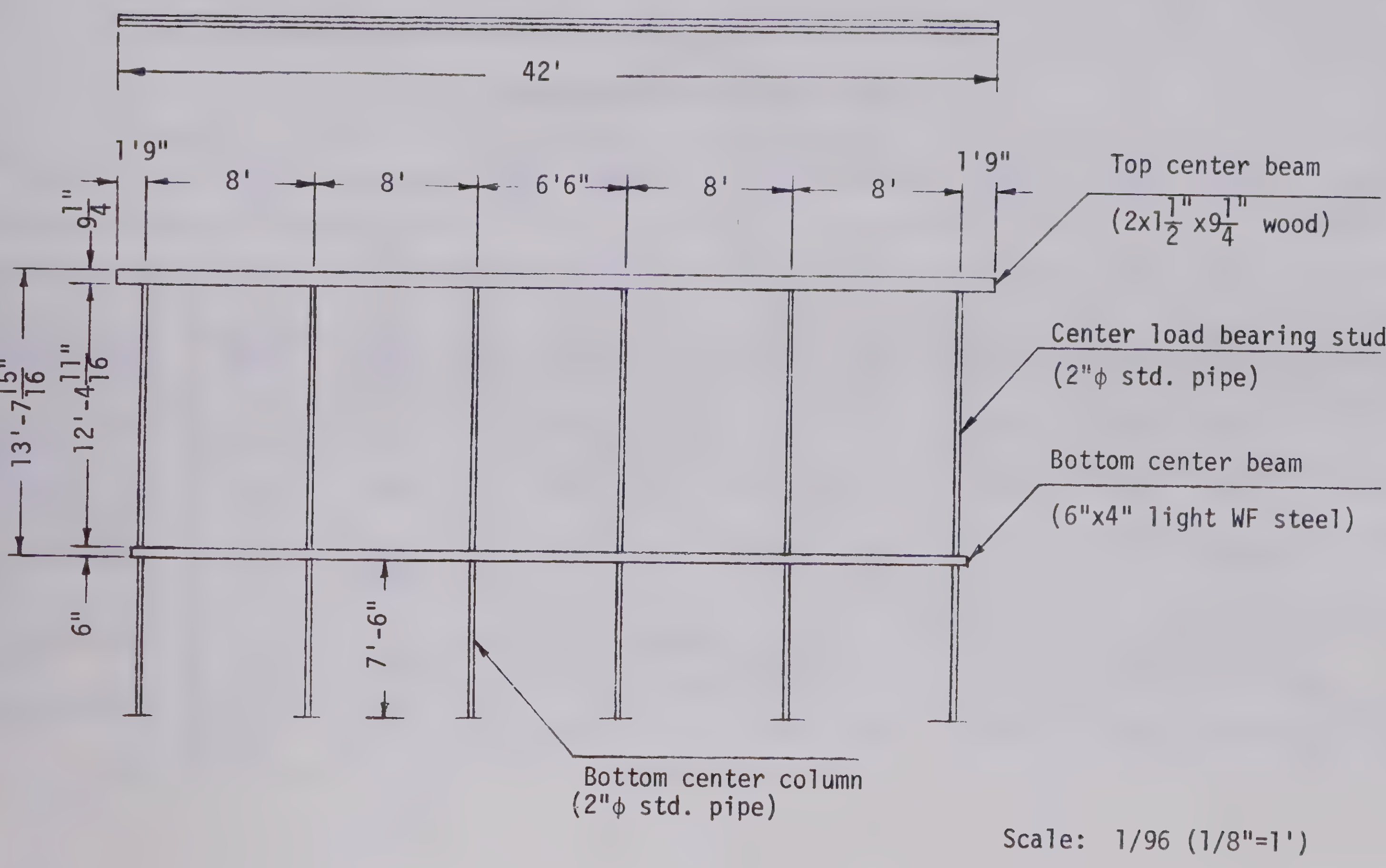
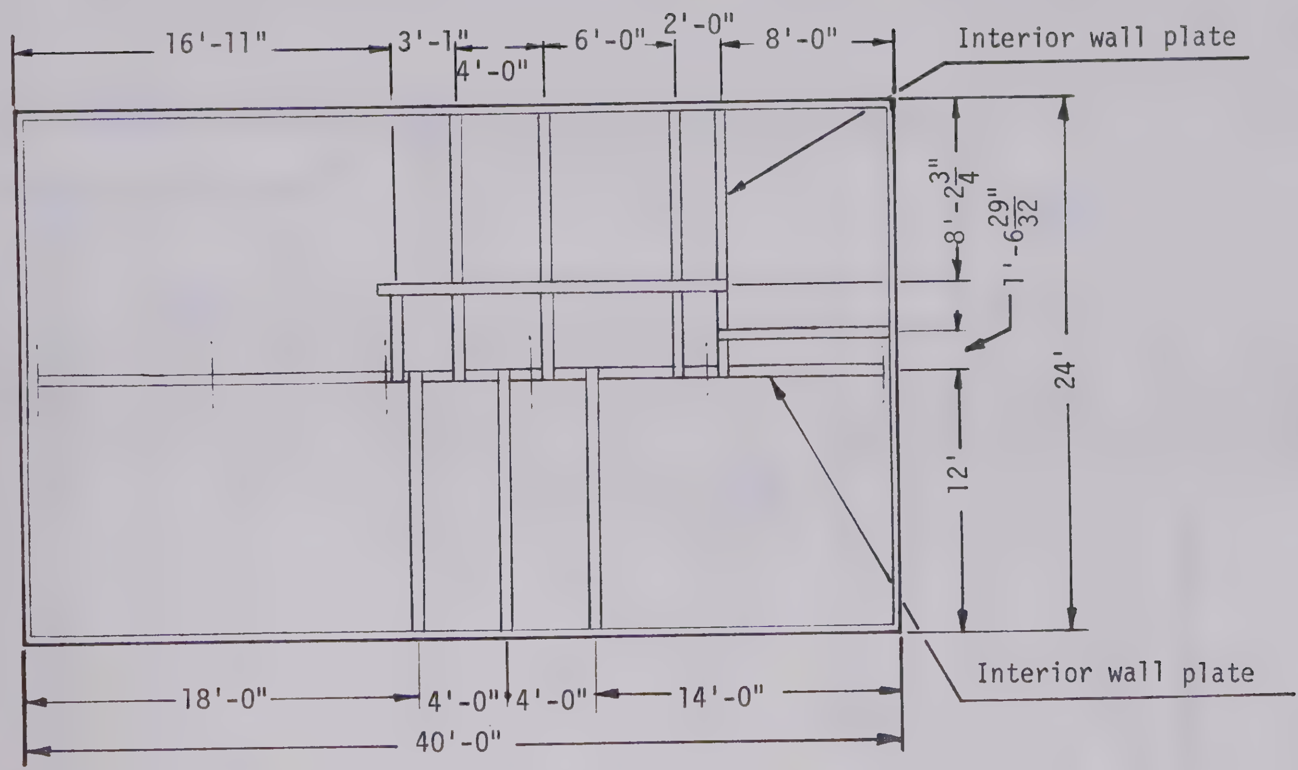


Figure 3.33 The center load bearing structure

Table 3.2

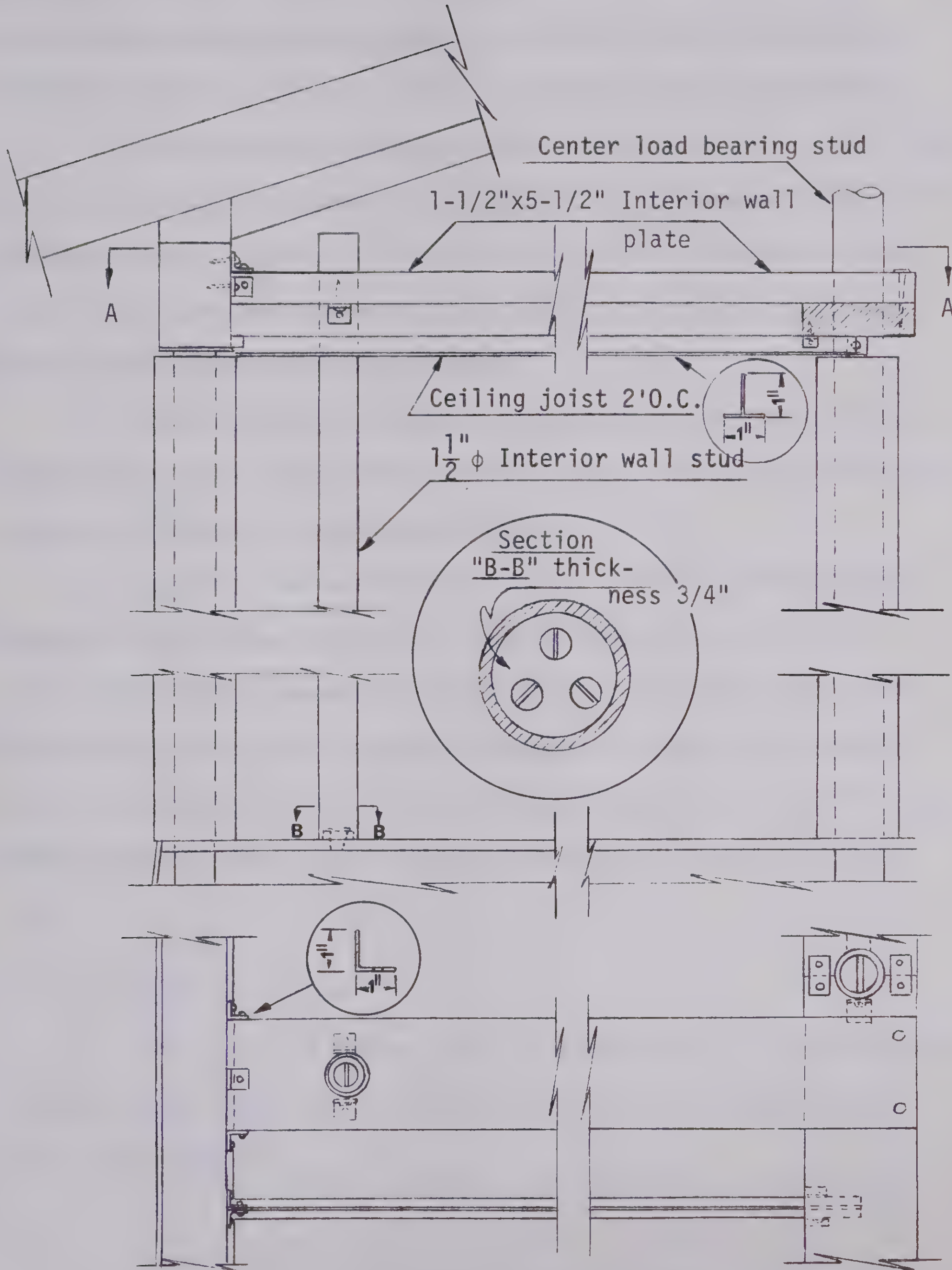
Feasible Alternatives for Structural Members

The structural member	Load and state of load	Materials	Required $S_x(in^3)$ $I_x(in^4)$	Chosen Section	Maximum span or size	Maximum deflection	Required quantity per home	Total weight per home	Total cost ($) per home	The chosen material
The top center beam	667 lbs/ft uniform	Steel	$S_x = 4.00$	6"x4"I	8' span	1/714	42 ft.	357 lbs.	71.40	
		Douglas Fir	$S_x = 42.7$	2 x 2"x10"	8' span	1/534	140 FBM	374 lbs.	50.50	*
The upper beam of the exterior wall	248 lbs/ft uniform	Steel	$S_x = 1.50$	6"x4"I	8' span	1/1900	132 ft.	1122 lbs.	224.40	
		Douglas Fir	$S_x = 15.82$	4"x6"	8' span	1/355	264 FBM	704 lbs.	96.00	*
The center load bearing stud	676 lbs/ft uniform	Steel	$I_x = 0.61$	2" ϕ std. pipe	13' long	--	78 ft.	285 lbs.	57.00	*
The exterior wall load bearing stud	248 lbs/ft uniform	Steel	$I_x = 0.095$	1-1/2 ϕ std. pipe	8.5' long	--	306 ft.	832 lbs.	166.40	*
The bottom center beam	734 lbs/ft uniform	Steel	$S_x = 4.40$	6"x4"I	8' span	1/628	40 ft.	340 lbs.	68.00	*
		Douglas Fir	$S_x = 47.0$	4 x 2"x8"	8' span	1/480	214 FBM	571 lbs.	77.00	
The bottom center column	734 lbs/ft + concent. loads	Steel	$I_x = 0.44$	2" ϕ std.	7.5' long	--	45 ft.	164 lbs.	33.00	*
		Douglas Fir	$I_x = 15.22$	6"x6"	7.5' long	--	144 FBM	384 lbs.	52.00	
The interior wall plate	300 lbs. concent. load	Douglas Fir	$S_x = 3.60$	2"x6"	12' span	1/534	144 FBM	384 lbs.	52.00	*



Scale: 1/96 (1/8"=1')

Figure 3.34 The Interior wall plate (960 ft^2 home)



Section "A-A"
Scale: 1/8(1/8"=1")

Figure 3.35 The connection of interior wall plate and ceiling joist

better material was chosen for each structural member. Various data and the chosen materials are shown in Table 3.2. All calculations related to the data shown in Table 3.2 are described in Appendix G.

The snow load is the most important factor for the roof design in Canada, because the snow load is generally the heaviest load to be carried by the structure. In this particular case the maximum magnitude of the snow load and wind load in Edmonton and Calgary were chosen for the necessary calculations.

Steel pipe was selected as the feasible alternative for the load bearing stud, because wood studs are not suited to the tolerances required for the wall locking mechanism.

For the interior wall plate, only wood was selected as the feasible alternative, because the interior wall plate should only resist a horizontal force not a vertical load and steel is not suitable for this particular purpose. Figure 3.34 shows one arrangement of the interior wall plate for a 960 square foot home. The detailed installation of the interior wall holding plate is shown in Figure 3.35.

3.5 The Extension System

The extension system chosen was designed to allow considerable flexibility to change the existing floor plan and to increase the total square footage.

Specification Requirements of the Desired Extension System

The chosen extension system was selected as optimal with regard to:

1. The minimum relocation of the existing walls;

2. The minimum number of new components which would be required for the extension;

3. Favorable acceptance, both economically and aesthetically, to the buyer with a minimum of final finishing on the site;

4. A minimum of disturbance to the tenant during the extension work;

5. Trouble free tolerances for ease in assembly; and

6. Ruggedness to withstand shipment over fairly large distances.

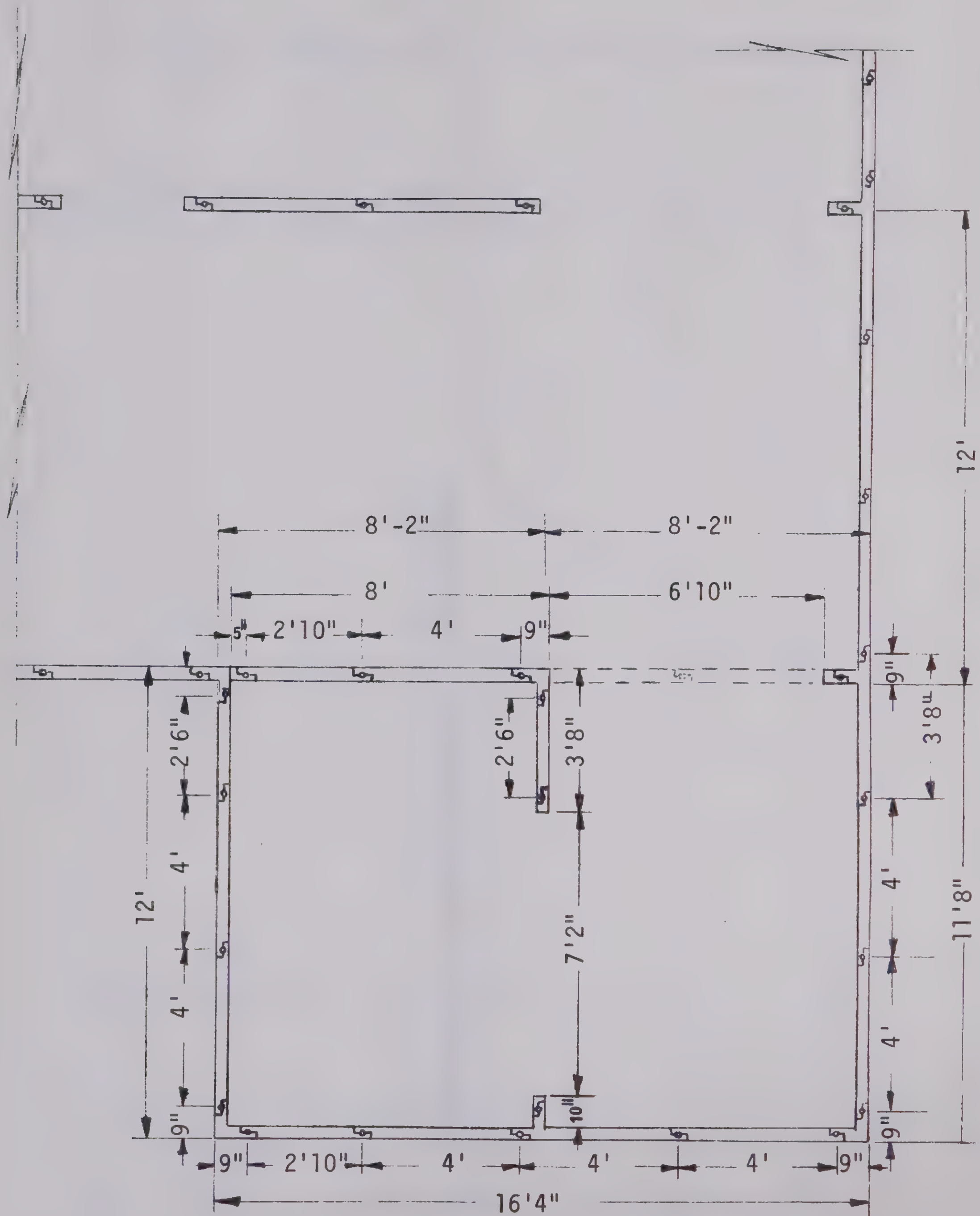
The Chosen Design

The extension system utilizes the same housing components as the basic floor plan of the original home.

The original floor plan can be extended on the same level or by the introduction of a split level extension.

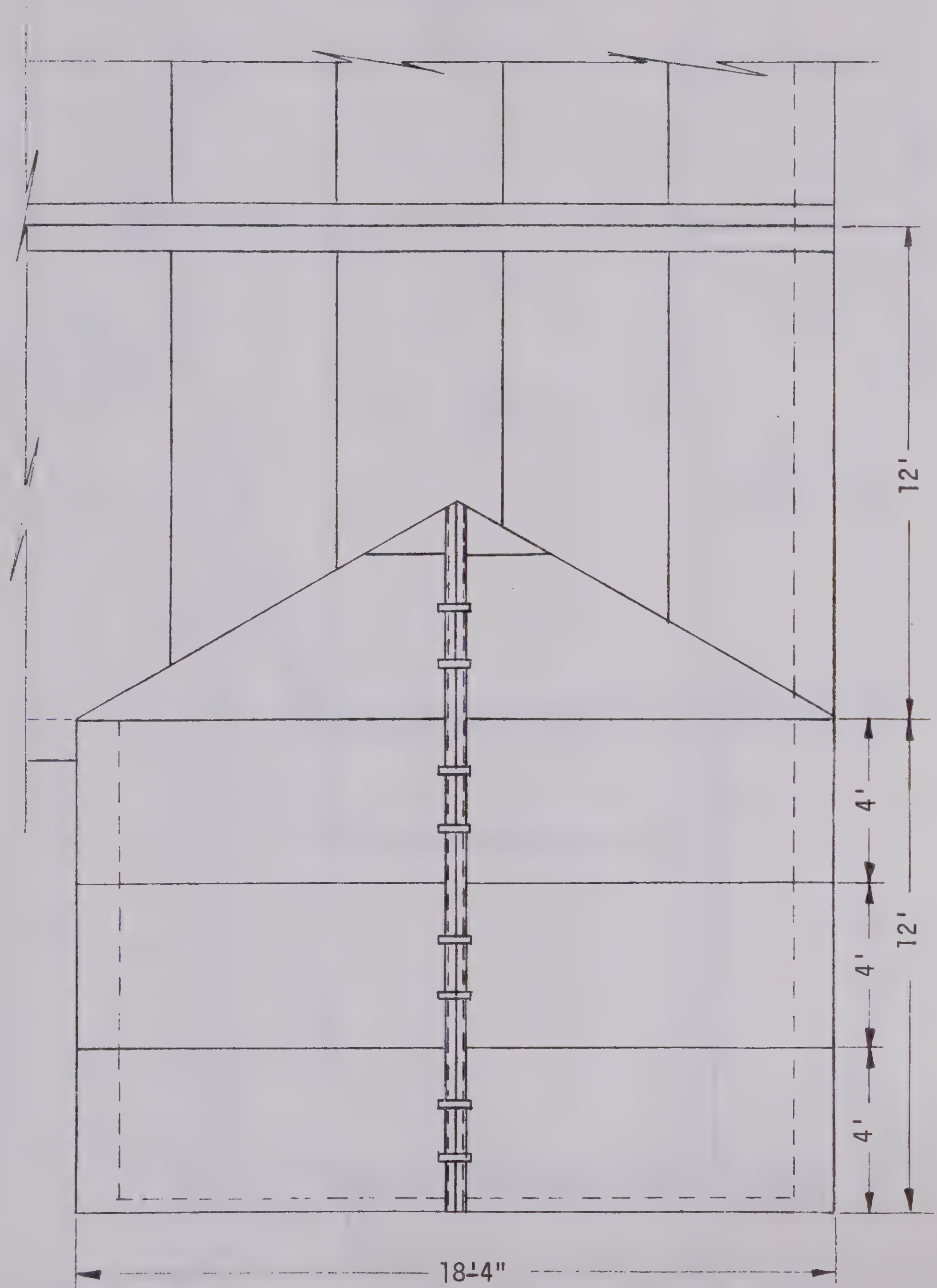
Figure 3.36 shows an arrangement of the wall panel extension on the same level in which a part of the original exterior wall panels are relocated and the new exterior and interior wall panels are installed. The roof extension and the floor extension are shown in Figure 3.37, 3.38 and 3.39 respectively. The details of a roof panel for the same level extension are shown in Figure 3.40. The length of the roof panel varies with the size of the extension.

The wall, the roof and the floor panel extensions on the sunken level are shown in Figure 3.41, 3.42, and 3.43 respectively. One advantage of the split level extension is that no extra design of the roof panel is required.



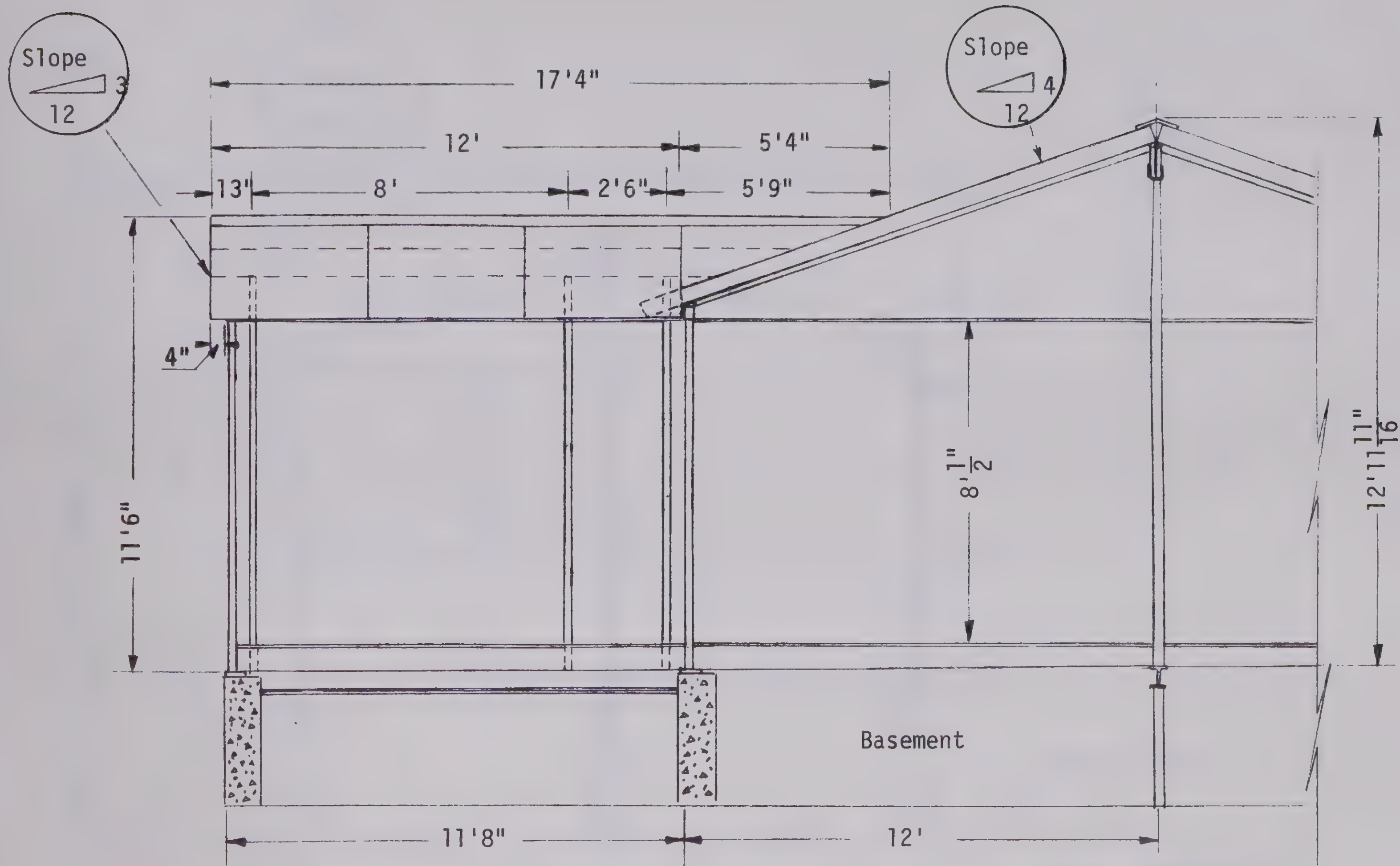
Scale: 1/48 (1/4"=1')

Figure 3.36 The wall panel extension: same level



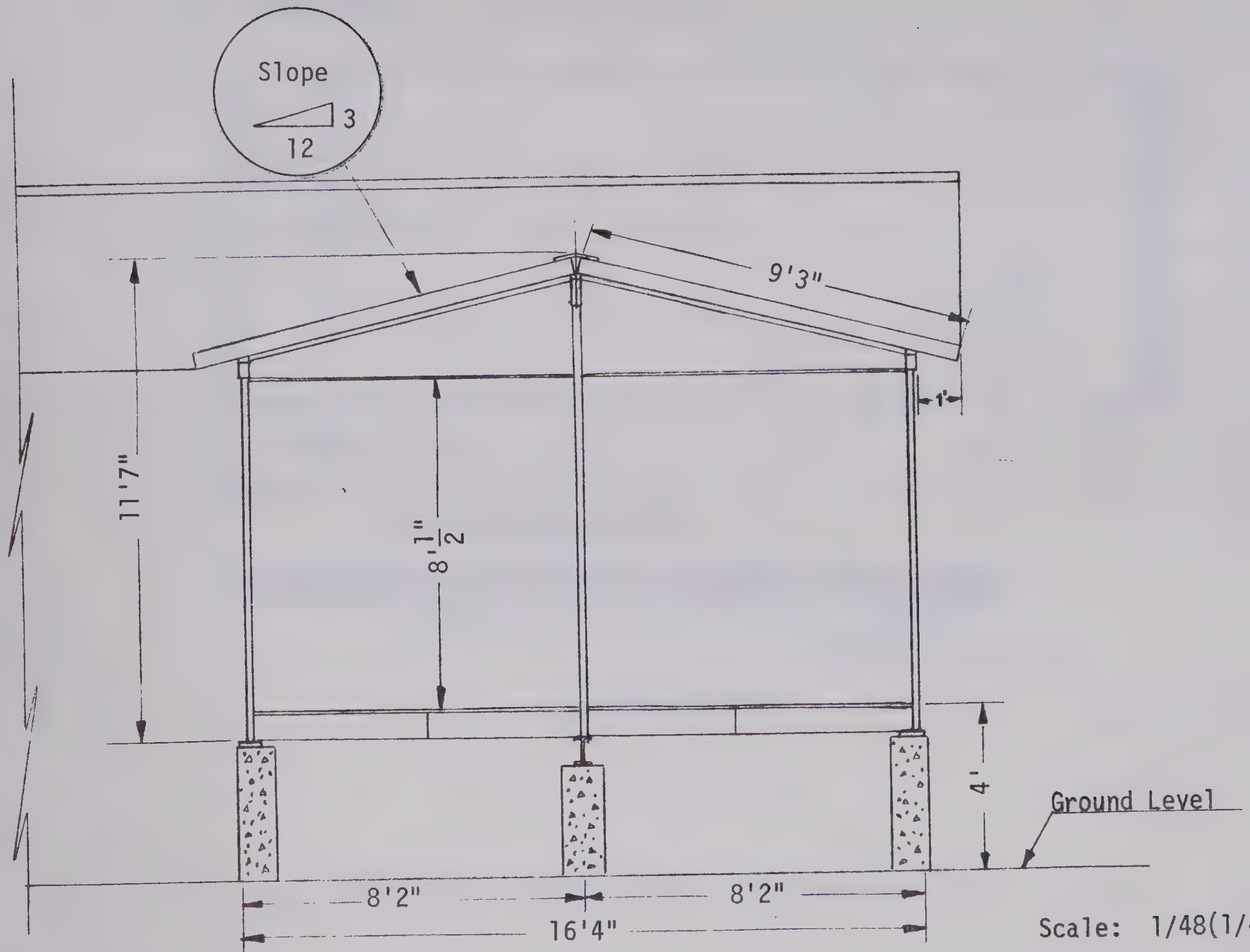
Scale: 1/48 (1/4"=1')

Figure 3.37 Top view of the roof panel extension: same level



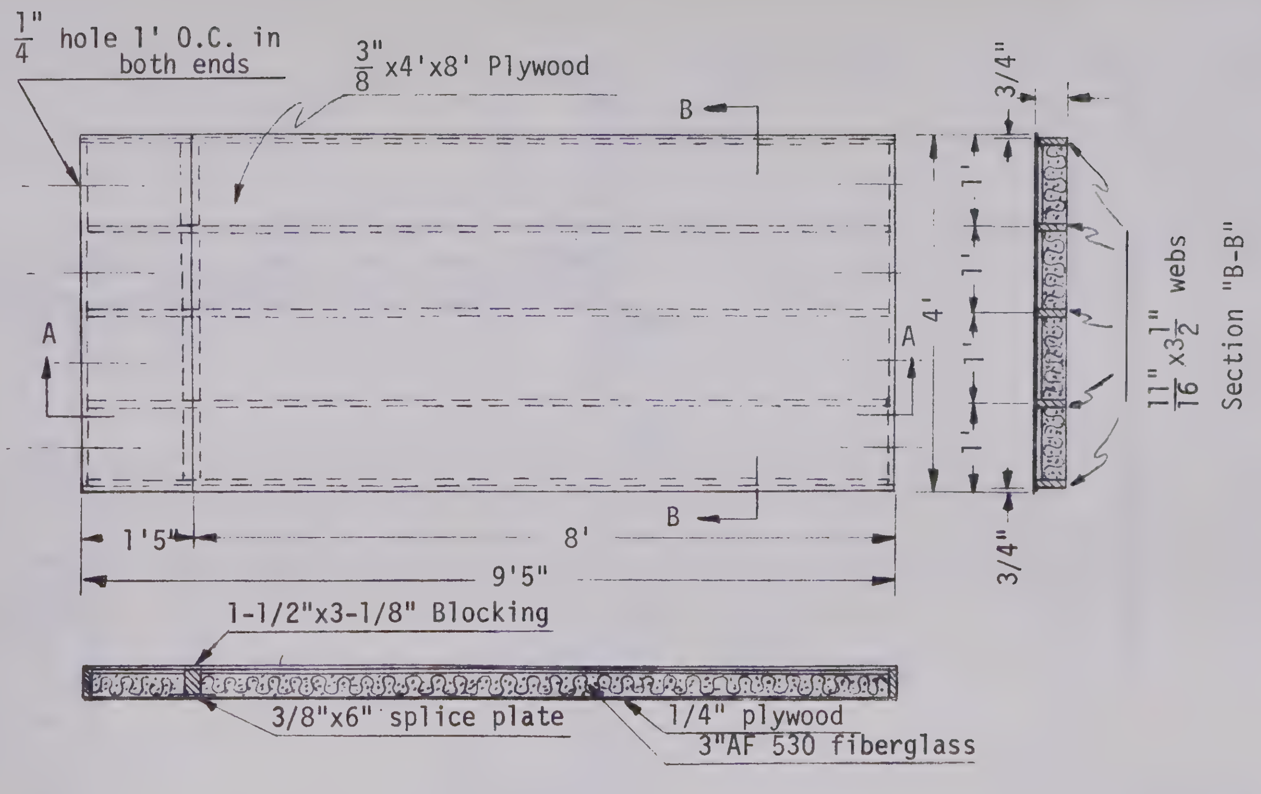
Scale: 1/48(1/4"=1')

Figure 3.38 The roof and the floor panel extension: same level



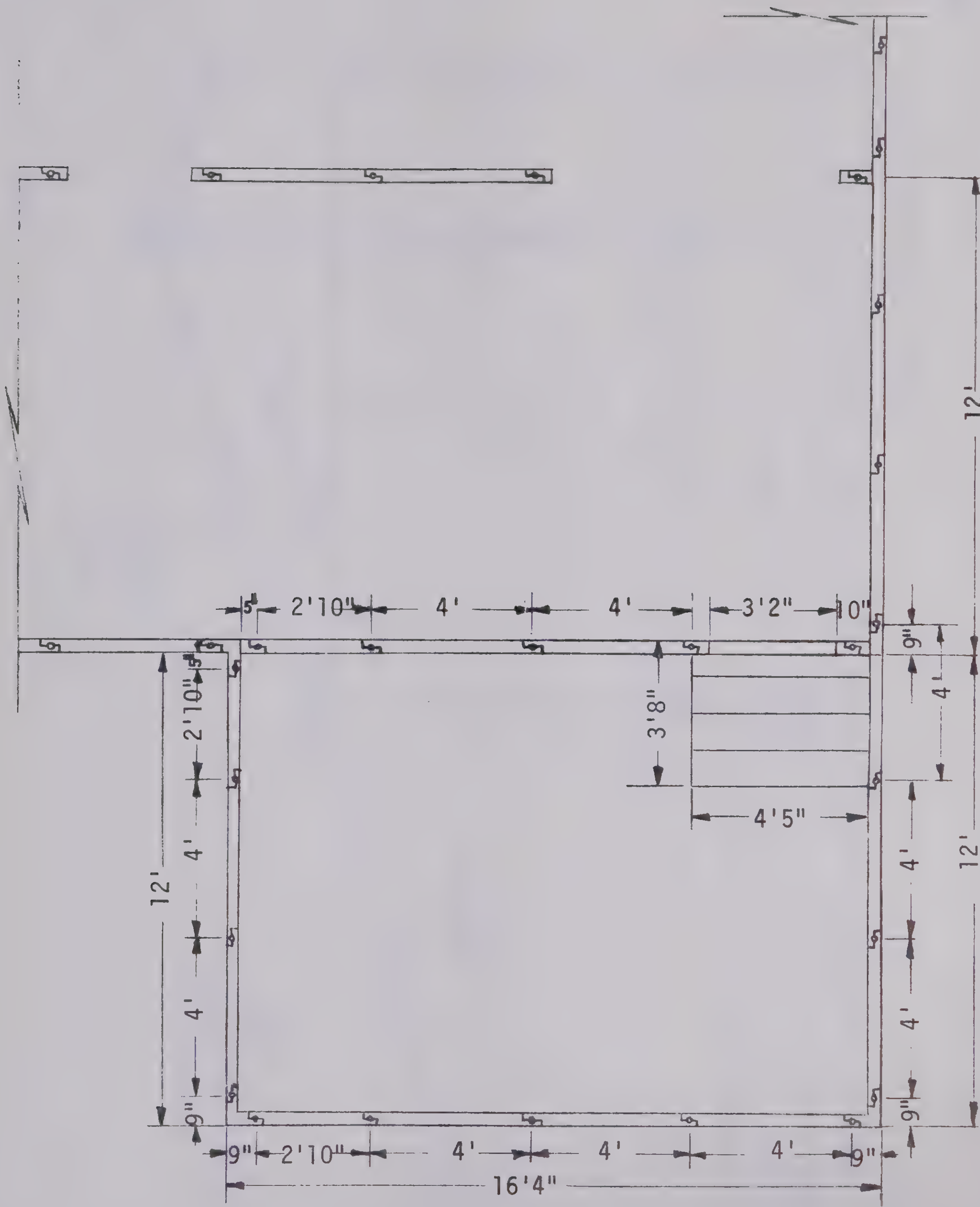
Scale: 1/48(1/4"=1')

Figure 3.39 The roof panel extension: same level



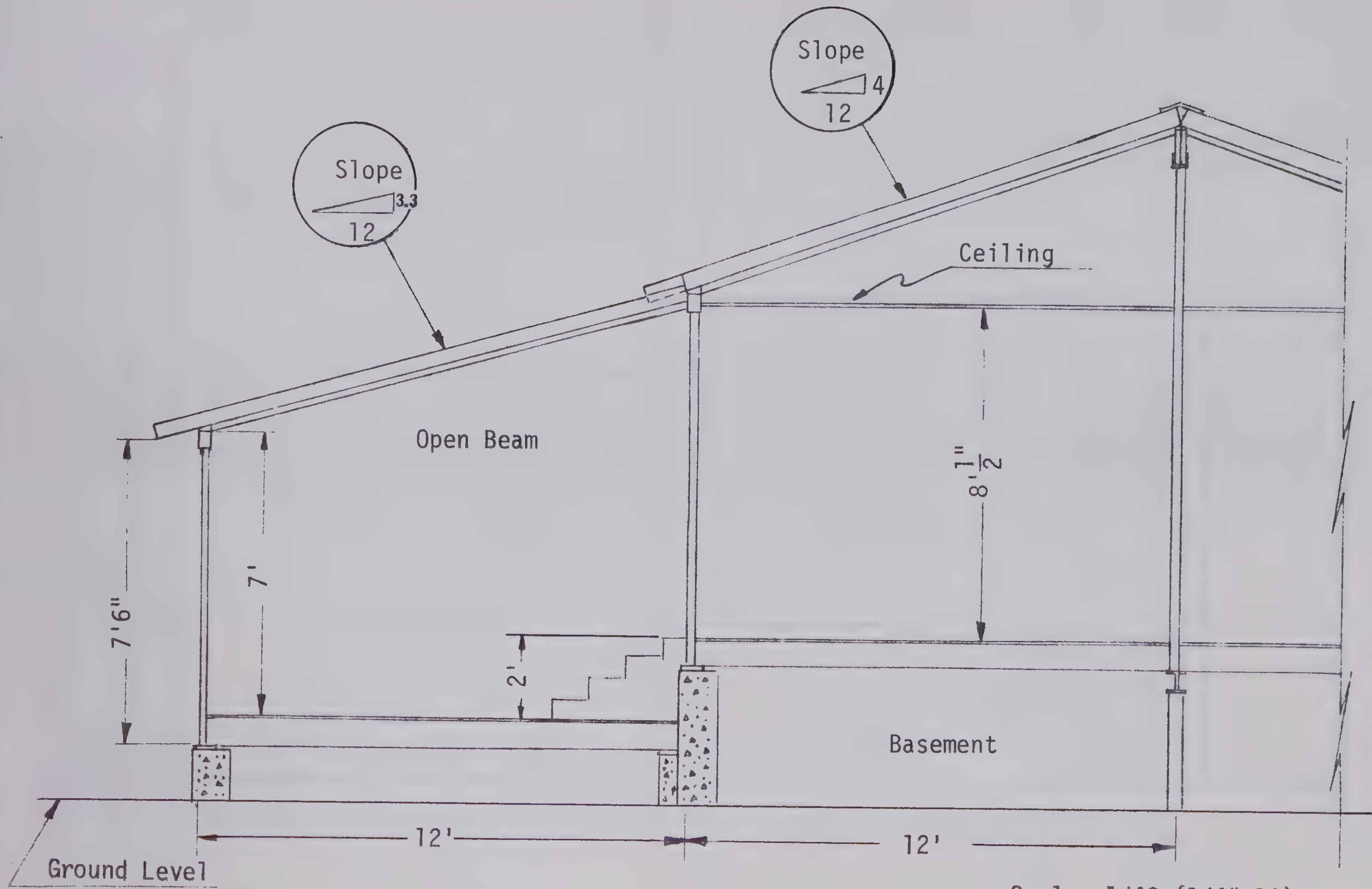
Scale: 1/24(1/2"=1')

Figure 3.40 The roof panel extension: same level



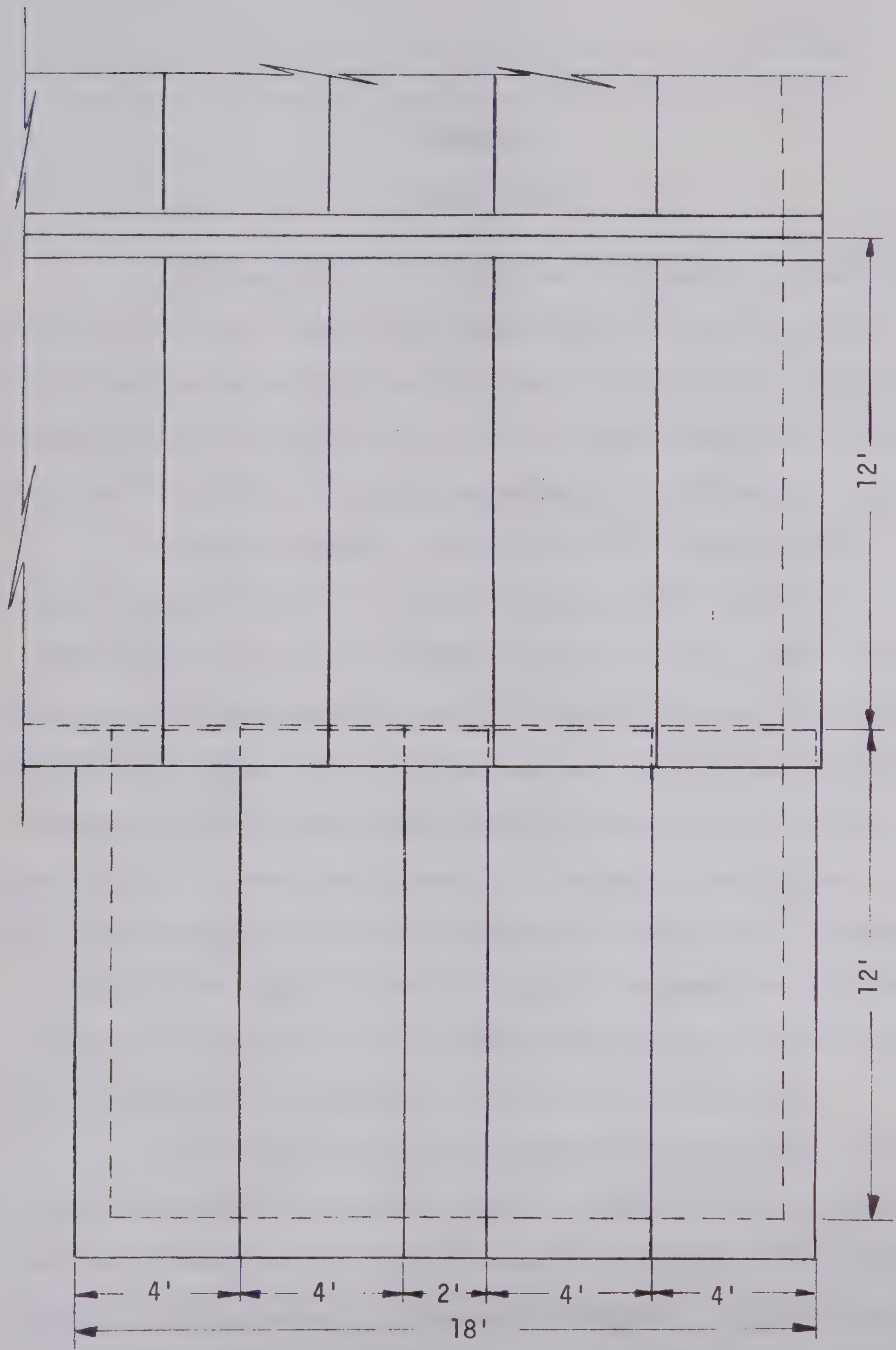
Scale: 1/48 (1/4"=1')

Figure 3.41 The wall panel extension: split level



Scale: 1/48 (1/4"=1')

Figure 3.42 The roof and the floor panel extension: split level



Scale: 1/48(1/4"=1')

Figure 3.43 Top view of the roof panel extension: split level

CHAPTER IV

CONCLUSIONS

The objective of this study was to develop a system of producing a functional home that is marketable and appealing to the tenant with major emphasis being placed on flexibility. The FLEXI-GROW housing system was selected as the chosen system for its simplicity and flexibility to change and expand with the family's needs.

For young married couples and/or low income families both a low down payment and relatively low monthly payments in the initial years are usually essential when purchasing a home. The FLEXI-GROW housing system should accomplish both of these major considerations to a greater degree than any other housing system on the market today. Payment for a FLEXI-GROW house should be completed earlier than in the case of a conventional house, with respect to the husband's age. All cost data used in this study represent average costs for dwellings in Canada. The exact cost of each housing component and the construction costs cannot be calculated before final selection of all materials and the design of the manufacturing process are completed.

The design of each housing component chosen should lend itself to a manufacturing process that is compatible with the mass production of homes and the on-site assembly in a minimum time and requiring a minimum amount of experienced manpower. The prefinished panels including windows and doors can be assembled easily on the site

by the chosen connecting and locking mechanisms. The chosen wall panels are not bearing the load and allow easy removal for flexibility to change the floor plan.

Several different kinds of housing components are required to assemble a FLEXI-GROW home and each component has its own function. In this study, the basic design of each housing component for the FLEXI-GROW housing system has been outlined using conventional building materials. An in depth study has not been conducted at this stage with respect to innovative materials and manufacturing processes. Before implementation of the FLEXI-GROW housing system further study should be pursued to insure that the most desirable materials and manufacturing processes are used.

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APPENDIX A

COST CALCULATIONS FOR THE FLEXI-GROW No. 1

The required cost calculations for the FLEXI-GROW No. 1 is estimated as follows:

1. Work specifications to be required for the FLEXI-GROW No. 1

   1.1 Nine panels should be relocated.

   1.2 One new door panel and one interior wall panel are required.

   1.3 Three folding doors should be relocated.

   1.4 Two new folding doors are required.

   1.5 Kitchen facilities to be removed for sale or to the basement.

   1.6 Minor repair for floor finishing (vinyl tile) is required.

   1.7 Minor painting work in the former kitchen area is required.

2. Estimated costs:

   2.1 Labor cost

Utility worker - 1 man x 4 hours x $4.50/hour	= $18.00
Panel relocators - 2 men x 8 hours x $4.50/hour	= $72.00
Helpers (Labors) - 4 men x 8 hours x $3.75/hour	= $120.00
Total	$210.00

2.2	Material cost (panels, vinyl tile and paint)	\$100.00
2.3	Overhead (30% of the direct labor cost)	63.00
2.4	Profit (20% of the installed cost)	75.00
2.5	Total cost	\$448.00 ≅ \$450.00 (in the year 0)

2.6 Estimated cost in the year 3;

$$\$450.00 \times \frac{17.35^*}{16.15} = 481.50 \cong \$500.00$$

*See Table 2.1.

APPENDIX B

CALCULATIONS FOR FORECASTING THE COST OF CONSTRUCTION AND LAND

To estimate the average construction and land costs for any given year, the least squares method [5] is used.

1. The average construction cost per square foot.

	X	Y	XY	X^2	Y^2
Year	Year No.	$			
1966	1	12.56	12.56	1	157.75
1967	2	13.04	26.08	4	170.04
1968	3	13.68	41.04	9	187.14
1969	4	14.62	58.48	16	213.74
1970	5	14.94	74.70	25	223.20
1971	6	15.44	92.64	36	238.39
	$\Sigma X = 21$	$\Sigma Y = 84.28$	$\Sigma XY = 305.50$	$\Sigma X^2 = 91$	$\Sigma Y^2 = 1190.26$

$$n = 6,\ \bar{x} = \frac{\Sigma x}{n} = \frac{21}{6} = 3.5\ ,\ \bar{Y} = \frac{\Sigma Y}{n} = \frac{84.28}{6} = 14.047$$

$$\Sigma x^2 = \Sigma x^2 - \frac{(\Sigma x)^2}{n} = 91 - \frac{(21)^2}{6} = 91 - \frac{441}{6} = 91 - 73.5 = 17.5$$

$$\Sigma y^2 = \Sigma Y^2 - \frac{(\Sigma Y)^2}{n} = 1190.26 - \frac{(84.28)^2}{6} = 1190.26 - 1183.85 = 6.41$$

$$\Sigma xy = \Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{n} = 305.5 - \frac{(21)(84.28)}{6} = 305.5 - 294.98 = 10.52$$

$$b = \frac{\Sigma xy}{\Sigma x^2} = \frac{10.52}{17.5} = 0.601$$

$$a = \overline{Y} - b\overline{X} = 14.047 - 0.601 \times 3.5 = 14.047 - 2.104 = 11.94$$

$$\therefore \quad \hat{Y} = a + bX = 11.94 + 0.601X$$

$$SE^* = \sqrt{\frac{\Sigma Y^2 - a\Sigma Y - b\Sigma XY}{n-2}} = \sqrt{\frac{1190.26 - 11.94 \times 84.28 - 0.601 \times 305.5}{6-2}}$$

$$= \sqrt{\frac{1190.26 - 1006.3 - 183.6}{4}} = \sqrt{\frac{0.36}{4}} = \sqrt{0.09} = \pm 0.3$$

2. The average land cost for NHA bungalows

	X	Y	XY	X^2	Y^2
Year	Year No.	$1,000			
1966	1	3.01	3.01	1	9.06
1967	2	3.16	6.32	4	9.99
1968	3	3.36	10.08	9	11.29
1969	4	3.62	14.48	16	13.10
1970	5	4.26	21.30	25	18.15
1971	6	4.89	29.34	36	23.91
	ΣX =21	ΣY = 22.30	ΣXY =84.53	ΣX^2 =91	ΣY^2 =85.50

*Standard Error of the Estimate

$$n = 6,\ \overline{X} = \frac{\Sigma X}{n} = \frac{21}{6} = 3.5\ ,\ \overline{Y} = \frac{\Sigma Y}{n} = \frac{22.30}{6} = 3.72$$

$$\Sigma x^2 = \Sigma X^2 - \frac{(\Sigma X)^2}{n} = 91 - \frac{(21)^2}{6} = 91 - \frac{441}{6} = 91 - 73.5 = 17.5$$

$$\Sigma y^2 = \Sigma Y^2 - \frac{(\Sigma Y)^2}{n} = 85.50 - \frac{(22.30)^2}{6} = 85.50 - 82.96 = 2.54$$

$$\Sigma xy = \Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{n} = 84.53 - \frac{(21)(22.30)}{6} = 84.53 - 78.05 = 6.48$$

$$b = \frac{\Sigma xy}{\Sigma x^2} = \frac{6.48}{17.5} = 0.37$$

$$a = \overline{Y} - b\overline{X} = 3.72 - 0.37 \times 3.5 = 3.72 - 1.295 = 2.425$$

$$\therefore\ \hat{Y} = a + bX = 2.425 + 0.37X$$

$$SE = \sqrt{\frac{\Sigma Y^2 - a\Sigma Y - b\Sigma XY}{n-2}} = \sqrt{\frac{85.5 - 2.425 \times 22.30 - 0.37 \times 84.53}{4}}$$

$$= \sqrt{\frac{85.5 - 54.078 - 31.276}{4}} = \sqrt{\frac{0.146}{4}} = \sqrt{0.0365} = \pm\ 0.191$$

APPENDIX C

INCOME TAX CALCULATIONS

The income tax on the bachelor suite income for the first three years is calculated as follows:

1. Assumptions

   1.1 The home owner is living in Alberta with a wife who is not working.

   1.2 The following calculation is based on 1971 individual income tax regulations.

   1.3 The home owner's monthly income from his salary is $600 per month.

2. Income Tax Calculations:

   2.1 Income

Salary	$7,200/yr. ($600/month)
Room rental	$1,320/yr. ($110/month)
Total	$8,520/yr

   2.2 Deductions

Basic personal exemption	$1,000
Married exemption	$1,000
Canada pension plan	86.40
Total deduction	$2,086.40

   2.3 Taxable income $6,433.60

2.4 Income tax

Federal tax	$1,174	
Provincial tax	$ 383.80	
Total tax	$1,557.80	(a)

If one does not have any income from room rental;

Taxable income	$5,113.60	
Income tax -		
Federal tax	$ 900	
Provincial tax	$ 282.20	
Total tax	$1,182.20	(b)

2.5 Income tax on the bachelor suite income;

(a) - (b) = $1,557.80 - $1,182.20 = $375.60/yr.

= $31.30/month

APPENDIX D

POSSIBLE ALTERNATIVES FOR THE PANEL LOCKING MECHANISM

Some of the alternatives studied with respect to the panel locking mechanism are as follows:

1. The fixed bolt locking mechanism

The bolt is fixed on the inside of the end stud of the wall panel for assembly on the building site. Figure D.1 shows the top view of the fixed bolt locking mechanism. Two of the major disadvantages as follows:

1. This locking mechanism creates additional problems and cost in the manufacturing process.

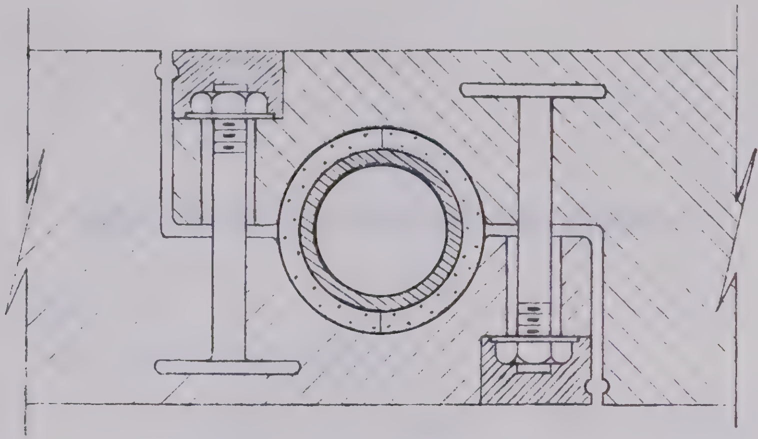
2. Considerable accuracy is required in locating the bolt hole to ensure easy assembly. The tolerances are therefore considered too close for a system of this nature.

2. The clip locking mechanism

Figure D.2 shows the over-all view of the clip locking mechanism. A steel clip can be used to hold the wall panel in place and it can be installed on the site by bending one end of the clip, however, it was considered inferior to the chosen locking mechanism because of the following reasons.

1. This item should be manufactured by a special order, therefore it may prove costlier.

2. The bending point may be weakened by repeated use.



Scale: 1/2

Figure D.1 The fixed bolt locking mechanism

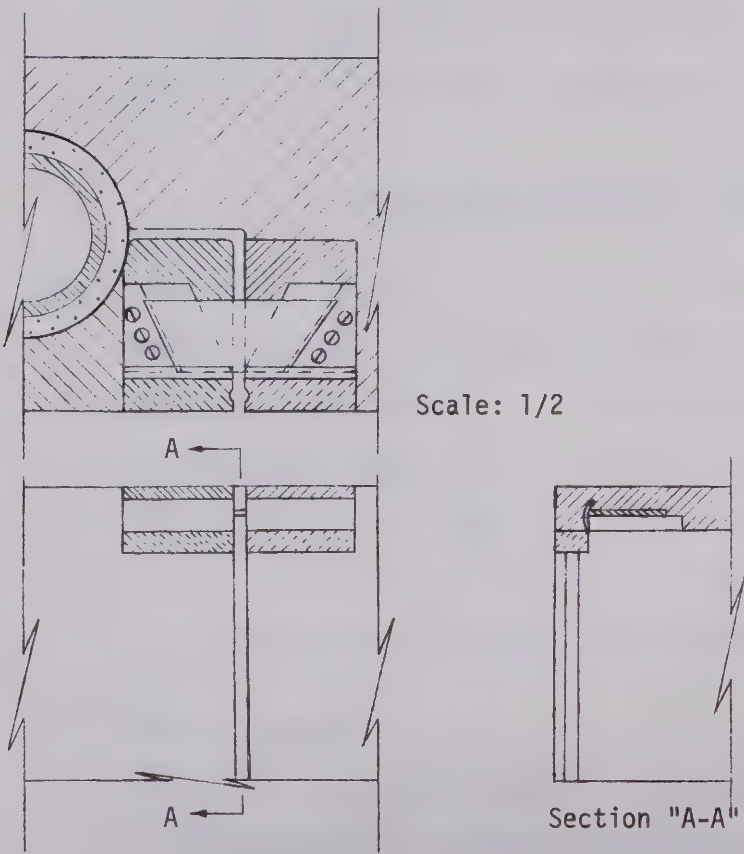


Figure D.2 The clip locking mechanism

APPENDIX E

WEIGHT OF THE FLEXI-GROW HOUSING COMPONENTS

1. Wall

1.1 Exterior Wall Panel

3/8"x4'x8'x2 pcs plywood : 1 ft^3x34 lbs/ft^3 = 34 lbs.

2"x4"x3.5'x3 pcs plates : 0.6x32 lbs/ft^3 = 19.2 lbs.

2"x4"x8' center stud : 0.45x32 lbs/ft^3 = 14.4 lbs.

2-1/2"x4'x8' insulation : 6.67x3 lbs/ft^3 = 20 lbs.

3-1/2"x7-1/2"x8' end stud : 1.28x32 lbs/ft^3 = 41 lbs.

129 lbs/panel

129 lbs/panelx32panels = 4128 lbs/960 ft^2 home

1.2 Interior Wall Panel

4mm(5/32")x4'x8'x2 pcs plywood : 0.832 ft^3x34 lb/ft^3 = 28.3 lbs.

2"x4"x3.5'x3 pcs plates : 0.6 ft^3x32 lbs/ft^3 = 19.2 lbs.

2"x4"x8' center stud : 0.45 ft^3x32 lbs/ft^3 = 14.4 lbs.

3-1/2"x7-1/2"x8' end stud : 1.28 ft^3x32 lbs/ft^3 = 41 lbs.

103 lbs/panel

103 lbs/panel x 20 panels = 2060 lbs/960 ft^2 home

1.3 Corner Connector

4"x19"x8' : 4.2 ft^3x34 lbs/ft^3 = 143 lbs/piece

143 lbs/piece x 4 pieces = 572 lbs/960 ft^2 home

2. Roof

2.1 Roof Panels

3/8"x4'x14'&5/16"x 4'x14' plywood : 3.21 ft^3x34 lbs/ft^3

= 109.2 lbs.

1"x4"x74'&2"x4"x10' webs: 2.72 ft^3x32 lbs/ft^3 = 87.1 lbs.

2-3/8"x4'x14' Insulation: 11 ft^3x2.3lbs/ft^3 = 25.3 lbs.

222 lbs/panel

222 lbs/panel x 21 panels = 4662 lbs/960ft^2 home

2.2 Rafters

2"x6"x14'x24 pcs : 28 ft^3x32 lbs/ft^3 = 896 lbs/960 ft^2 home

2.3 Roofing materials

Asphalt Shingles : 210 lbs/100 ft^2x1160 ft^2 = 2436 lbs/

960 ft^2 home

Scotch-Clad Deck Coating System: 50 lbs/100 ft^2 x

1160 ft^2 = 580 lbs/960 ft^2 home

3. Ceiling

3.1 Ceiling Tile

1/4"x24'x40' : 20 ft^3x20 lbs/ft^3 = 400 lbs/960 ft^2 home

3.2 Ceiling Joist

1"x1"x12' : 10 lbs/pc x 40 pcs = 400 lbs/960ft^2 home

4. Floor

4.1 Floor Panel

1/2"x4'x11.7' plywood x20 pcs: 39 ft^3x34 lbs/ft^3 = 1320 lbs.

2"x8"x11.7' joistx62 pcs: 80 ft^3x32 lbs/ft^3 = 2560 lbs.

3880 lbs/960 ft^2 home

The average weight of panel: $\frac{3880}{20}$ = 194 lbs/panel

4.2 Carpet for living room and master bedroom

350 ft^2 : 15 ft^3x82 lbs/ft^3 = 1230 lbs/960 ft^2 home

4.3 Vinyl for other area except living room and master bedroom

540 ft^2 : 2.8 ft^3x94 lbs/ft^3 = 260 lbs/960 ft^2 home

5. Structures

5.1 Top Center Beam

2"x10"x2 pcs of Douglas Fir : 140 FBMx2.67 lbs/FBM* = 374 lbs/960 ft^2 home

5.2 Upper beam of the exterior wall stud

4"x6" of Douglas Fir: 264 FBMx2.67 lbs/FBM = 704 lbs/960 ft^2 home

5.3 Center Load Bearing Stud

2"ϕ standard pipe: 3.65 lbs/ft x 13 ft/pc x 6 pcs = 285 lbs/960 ft^2 home

5.4 Exterior Wall Stud

1-1/2"ϕ standard pipe: 2.72 lbs/ft x8.5 ft/pc x 36 pcs. = 832 lbs/960 ft^2 home

5.5 Interior Wall Stud

1-1/2"ϕ standard pipe:

2.72 lbs/ft x 8.5 ft/pc x 25 pcs = 578 lbs/960 ft^2 home

5.6 Interior Wall Holding Plate

2"x6"x12' wood : 32 lbs/pcx12 pcs = 384 lbs/960 ft^2 home

5.7 Bottom center beam

6"x4" I beam : 8.5 lbs/ftx40 ft. = 340 lbs/960 ft^2 home

---

*Board-Feet, 1 FBM = 1 ft x 1 ft x 1 in.

5.8 Bottom Center Column

2"ϕ standard pipe: 3.65 lbs/ftx7.5 ft/pc x 6 pcs =

164 lbs/960 ft^2 home

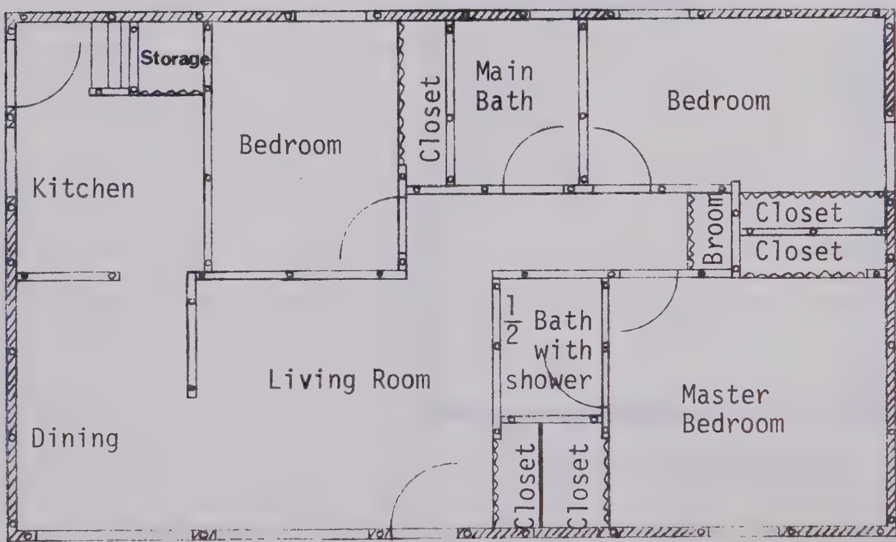
5.9 Sill Plate

2"x6"x12' wood : 32 lbs/pc x 11 pcs = 352 lbs/960 ft^2home

APPENDIX F

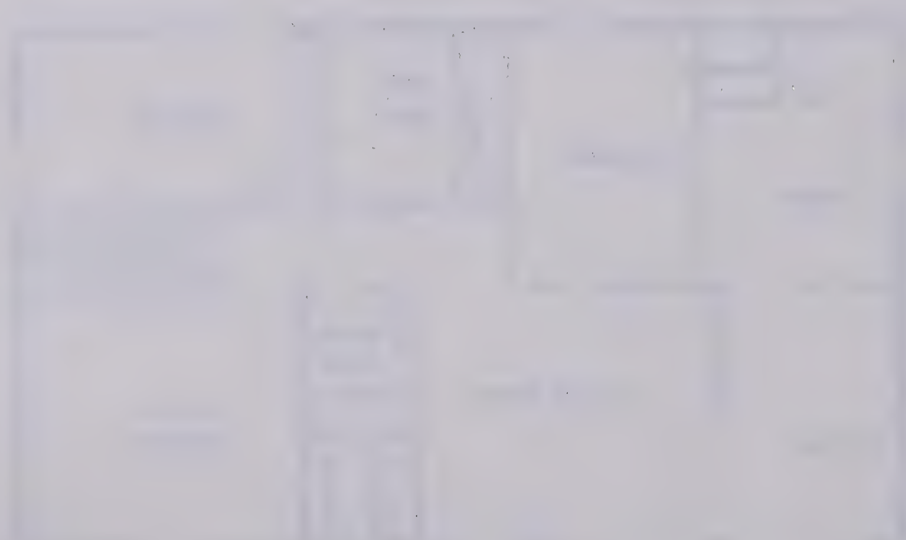
POSSIBLE ALTERNATIVE FLOOR PLANS

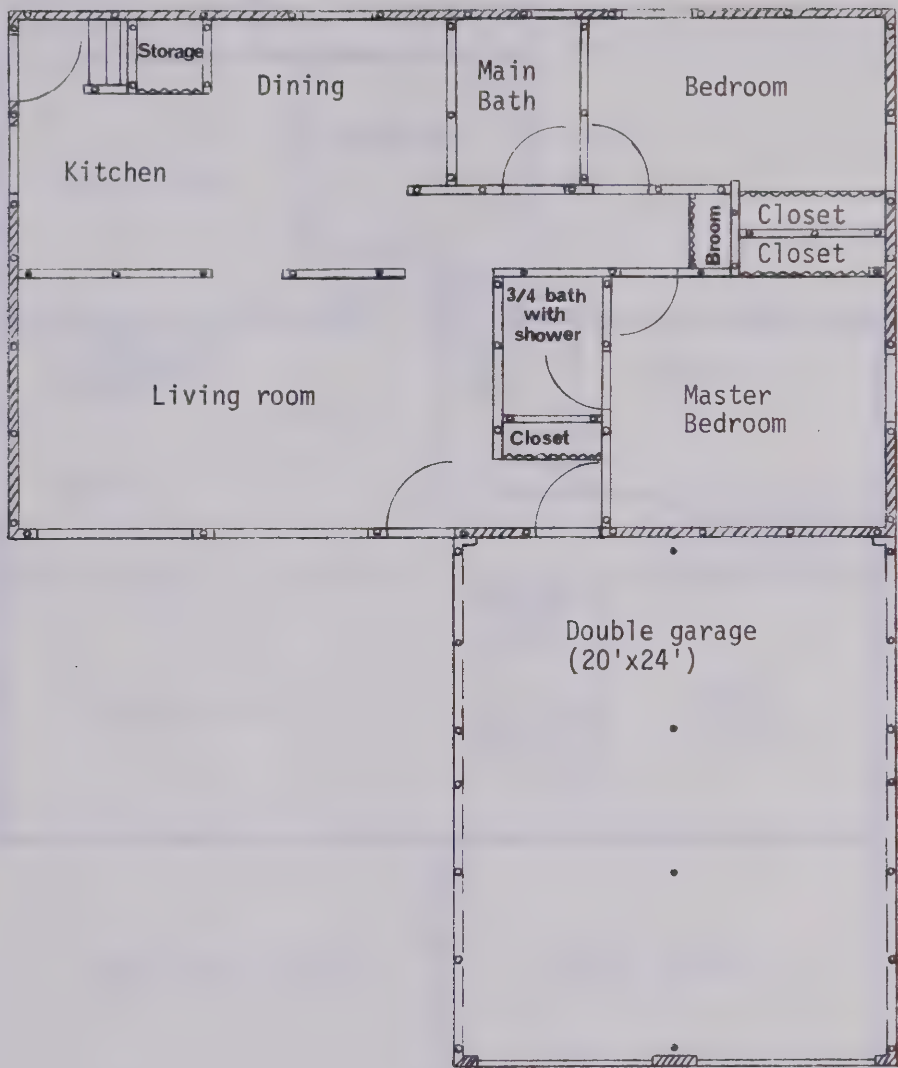
There are many possible alternative floor plans available, within the FLEXI-GROW housing system. Some of these plans are included in this section.



Scale: 1/96 (1/8"=1')

Figure F.1 960 square feet (40'x24') three bedroom floor plan





Scale: 1/96 (1/8"=1')

Figure F.2 960 square feet (40'x24') two bedroom floor plan and a double garage (20'x24')

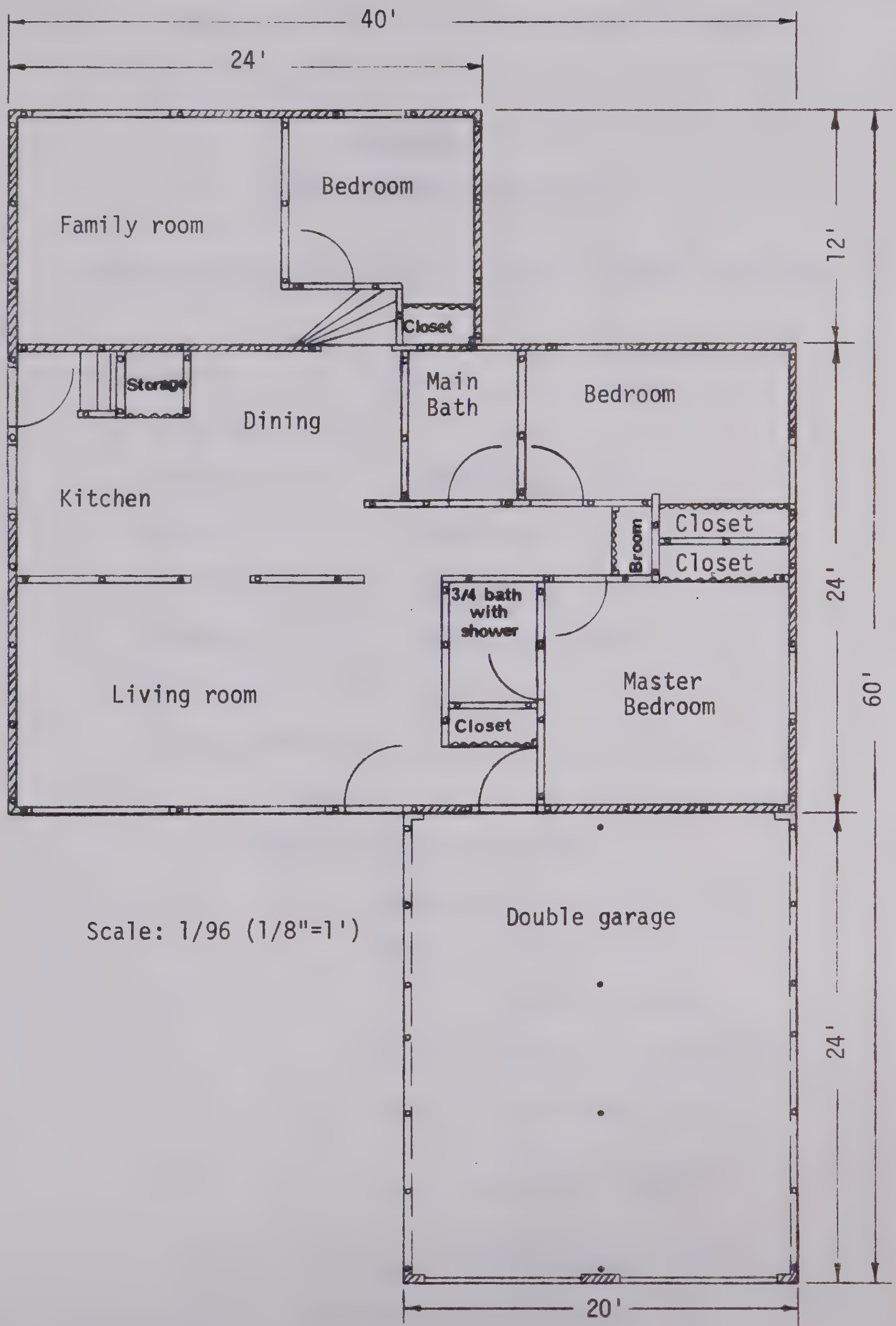


Figure F.3 1248 square feet three bedroom floor plan including 288 square foot extension, and a double garage

APPENDIX G

CALCULATIONS FOR STRUCTURES

The following calculations are based on a 960 square foot home.

1. Roof Load

1.1 Dead load of roof

Roof panels	4662 lbs.
Rafter	896 lbs.
Roofing material	2436 lbs.
Total	7994 lbs ≅ 4 tons

1.2 Snow load and wind load

1.2.1 Snow load

$S = C_s . q$

where S: design snow load

q: ground snow load

location; Edmonton 27 psf

Calgary 19 psf

27 psf is chosen for calculation

C_s: snow load coefficient [17]

$$C_s = 1.25\ (0.8 - \frac{18.5-30}{50})$$

$$= 1.25(0.8+0.23) \cong 1.3$$

S: 1.3x27 psf = 35.1 psf

Total snow load = 35.1 psf x 1160 ft^2 (roof area)

= 40,716 lbs ≅ 20.4 tons

If the roofs are exposed to the wind, the value of C_s is reduced by 25%, that is, total snow load would be 15.3 tons

1.2.2 Wind Load

$p = q.C_e.C_g.C_p$ [17]

where p: design external pressure

q: reference velocity pressure

location; Edmonton 10.7 psf

Calgary 11.3 psf

C_e: exposure factor, 1.0

C_g: gust effect factor, 2.5

C_p: external pressure coefficient, 0.7

p = 11.3 psf x 1.0 x 2.5 x 0.7 = 19.78 psf (on the vertical surface)

The pressure on the roof which has the slope 4/12:

p' = 19.78 psf x 0.45* = 8.89 psf

Total wind effect on the roof:

$$8.89 \text{ psf} \times \frac{1160 \text{ ft}^2}{2} = 5156 \text{ lbs} \cong 2.6 \text{ tons}$$

1.2.3 Total load of snow and wind

Snow load + wind load = 15.3 + 2.6 = 17.9 tons

17.9 tons is less than the maximum snow load, 20.4 tons, therefore 20.4 tons is chosen.

1.3 Total load of roof

Dead load + snow and wind load = 24.4 tons

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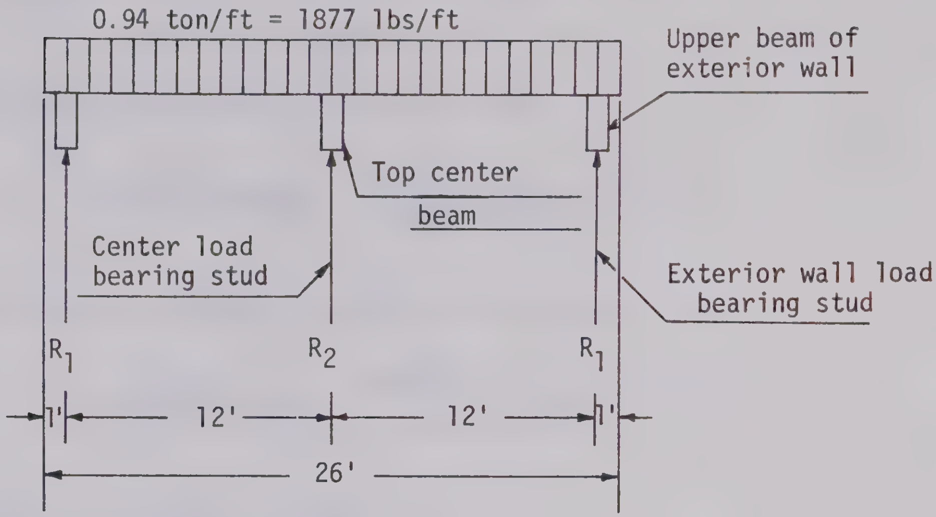
*See page 334 of [19].

1.4 Load distribution on the center and side walls

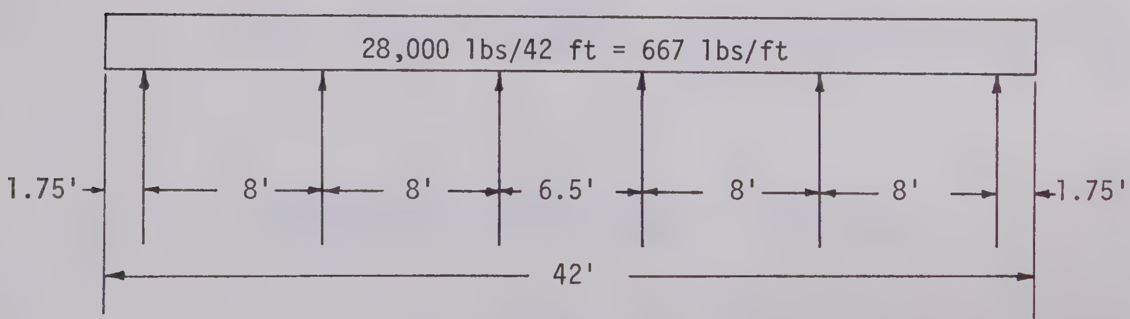


$$R_2 = (10/8)^* \times 1877 \text{ lbs/ft} \times 12 \text{ ft}$$

$$- (2 \times 0.5 \text{ ft} \times 1877 \text{ lbs/ft})/12.5 \text{ ft} = 28{,}000 \text{ lbs.}$$

$$R_1 = (26 \text{ ft} \times 1877 \text{ lbs/ft} - 28{,}000 \text{ lbs})/2 = 10{,}400 \text{ lbs.}$$

1.5 Top center beam



*See [4].

Maximum bending moment:

$$M_{max} \leq 0.125\ \omega\ell^2 = 0.125 \times 667\ \text{lbs/ft} \times (8\ \text{ft})^2$$

$$= 5{,}336\ \text{lb-ft} = 64{,}032\ \text{lb-in}$$

Required section modulus for steel beams:

$$S_x = \frac{M_{max}}{\text{Allowable stress}} = \frac{64{,}032\ \text{lb-in}}{16{,}000\ \text{lb/in}^{2}*} = 4.0\ \text{in}^3$$

Required section modulus for Douglas Fir wood:

$$S_x = \frac{M_{max}}{\text{Allowable stress}} = \frac{64{,}032\ \text{lb-in}}{1{,}500\ \text{lb/in}^{2}**} = 42.7\ \text{in}^3$$

Sections of possible alternatives:

Steel beam; 4"x4"I, WF13, $S_x = 5.2\ \text{in}^3$, 13 lbs/ft

6"x4"I,Light, $S_x = 5.07\ \text{in}^3$, 8.5 lbs/ft

Douglas Fir; 2x3"x8", $S_x = 43.8\ \text{in}^3$, 10.7 lbs/ft

2x2"x10", $S_x = 43.6\ \text{in}^3$, 8.9 lbs/ft

Maximum deflections (Allowable deflection = 1/240):

$$6\text{"x4"I, steel; } \delta = \frac{5.W.\ell^3}{384.E.I_x} = \frac{5\text{x}667\ \text{lbs/ftx}8\ \text{ft x }(96\ \text{in})^3}{384\text{x}30{,}600{,}000\ \text{lbs/in}^2\text{x}14.8\ \text{in}^4}$$

$$= 0.14\ \text{in.}$$

$$\frac{\text{Deflection}}{\text{Span}} = \frac{0.14\ \text{in.}}{8\ \text{ft x } 12\ \text{in/ft}} = 0.0014 = \frac{1}{714}$$

$$2\text{x}2\text{"x}10\text{" wood; } \delta = \frac{5.W.\ell^3}{384.E.I_x} =$$

$$\frac{5\text{x}667\ \text{lbs/ft x } 8\ \text{ft x }(96\ \text{in})^3}{384 \text{ x } 1{,}760{,}000\ \text{lbs/in}^2 \text{ x } 2 \text{ x } 98.93\ \text{in}^4}$$

$$= 0.18\ \text{in.}$$

---

*See page 6-31 of [4].
**See the table 1-3 of [10].

$$\frac{\text{Deflection}}{\text{Span}} = \frac{0.18 \text{ in}}{8 \text{ ft x } 12 \text{ in/ft}} = 0.0018 = \frac{1}{534}$$

Weight and Cost:

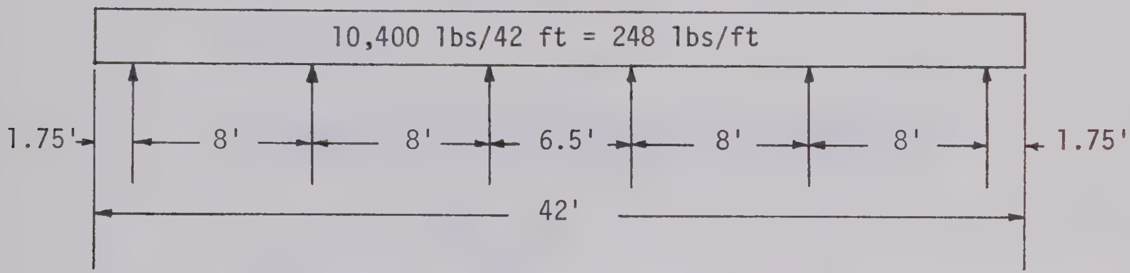
6"x4" I steel; 8.5 lbs/ft x 42 ft. = 357 lbs.

357 lbs x \$0.20/lb = \$71.40

2x2"x10" wood; 8.9 lbs/ft x 42 ft = 374 lbs.

140 FBM*** x \$0.36/FBM = \$50.50

1.6 Upper beam of the exterior wall



Maximum bending moment:

$$M_{max} \leq 0.125\ \omega\ell^2 = 0.125 \text{x} 248 \text{ lbs/ft x } (8 \text{ ft})^2$$

$$= 1{,}984 \text{ lb-ft} = 23{,}808 \text{ lb-in}$$

Required section modulus for steel beam:

$$S_x = \frac{23{,}808 \text{ lb-in}}{16{,}000 \text{ lbs/in}^2} = 1.5 \text{ in}^3$$

Required section modulus for Douglas Fir wood:

$$S_x = \frac{23{,}808 \text{ lb-in}}{1{,}500 \text{ lbs/in}^2} = 15.82 \text{ in}^3$$

***FBM = Board-feet, 1FBM = 1 ft x 1 ft x 1"

Sections of possible alt3rnatives:

Steel beam; 6"x4"I, Light, S_x = 5.07 in^3, 8.5 lbs/ft

Douglas Fir; 4"x6" S_x=17.65 in^3, 5.33 lbs/ft

Maximum deflections (allowable deflection = 1/240):

6"x4" I, steel;

$$\delta = \frac{5.W.\ell^3}{384.E.I_x} = \frac{5\text{x}248 \text{ lbs/ft x } 8 \text{ ft x } (96 \text{ in})^3}{384\text{x}30{,}600{,}000 \text{ lbs/in}^2\text{x}14.8 \text{ in}^4}$$

$$= 0.05 \text{ in.}$$

$$\frac{\text{Deflection}}{\text{Span}} = \frac{0.05 \text{ in}}{8 \text{ ft x } 12 \text{ in}} = 0.00053 = \frac{1}{1900}$$

4"x6" wood;

$$\delta = \frac{5.W.\ell^3}{384.E.I_x} = \frac{5\text{x}248 \text{ lbs/ft x } 8 \text{ ft x } (96 \text{ in})^3}{384\text{x}1{,}760{,}000 \text{ lbs/in}^2 \text{ x } 48.53 \text{ in}^4}$$

$$= 0.27 \text{ in.}$$

$$\frac{\text{Deflection}}{\text{Span}} = \frac{0.27 \text{ in}}{8 \text{ ft x } 12 \text{ in}} = 0.0028 = \frac{1}{355}$$

Weight and cost:

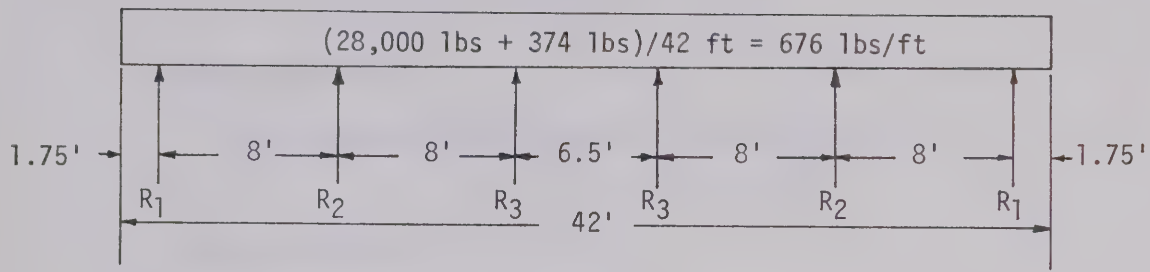
6"x4" I steel; 8.5 lbs/ft x 132 ft = 1122 lbs.

1122 lbs x \$0.20/lb = \$224.40

4"x6" wood; 533 lbs/ft x 132 ft = 704 lbs.

264 FBM x \$0.36/FBM = \$96.00

1.7 Center load bearing stud



Maximum reaction is R_1 or R_2:

$$R_2 = \left(\frac{23+20}{38}\right) \omega\ell^* = (43\text{x}676 \text{ lbs/ft x } 8 \text{ ft})/38 = 6120 \text{ lbs.}$$

$$R_1 = (15/38)^* \text{ x}676 \text{ lbs/ft x } 8 \text{ ft} + 1.75 \text{ x } 675 \text{ lbs} = 3318 \text{ lbs.}$$

Required area of section for steel:

$$A = \frac{R_2}{\text{allowable stress}} = \frac{6120 \text{ lbs}}{16{,}000 \text{ lbs/in}^2} = 0.39 \text{ in}^2$$

Required moment of inertia:

$$I = \frac{P_{cr}.\ell^2.S}{n.\pi^2.E} \quad *$$

where n = 4; end condition; both ends fixed

S = 5; safety factor [19]

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*see [4].

$$I = \frac{6120 \text{ lbs} \times (13 \text{ ft} \times 12 \text{ in/ft})^2 \times 5}{4 \times (3.14)^2 \times 30{,}600{,}000 \text{ lbs/in}^2} = 0.61 \text{ in}^4$$

Chosen material:

2"ϕ standard steel pipe; $I_x = 0.666 \text{ in}^4$

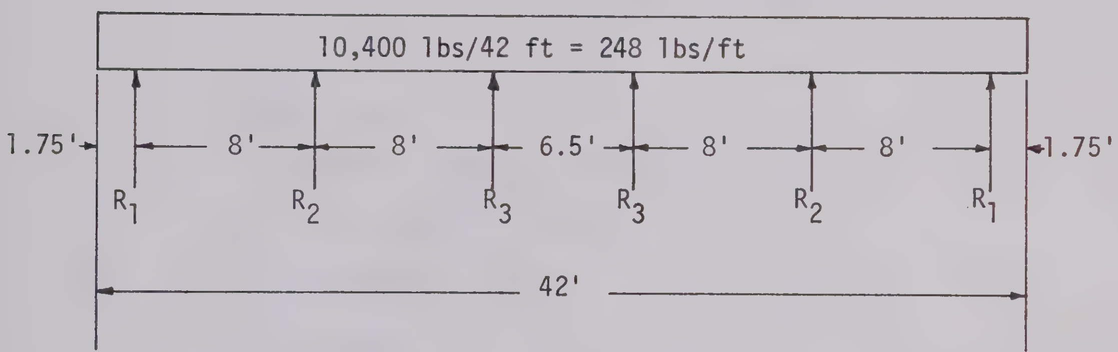
$A = 1.08 \text{ in}^2$

Weight and cost

3.65 lbs/ft x 78 ft = 285 lbs.

285 lbs x \$0.20/lb = \$57.00

1.8 Exterior wall load bearing stud



Max reaction is R_2:

$$R_2 = \left(\frac{23+20}{38}\right) \omega\ell = (43 \times 248 \text{ lbs/ft} \times 8 \text{ ft})/38 = 2245 \text{ lbs.}$$

Required area of section for steel:

$$A = \frac{R_2}{\text{Allowable stress}} = \frac{2{,}245 \text{ lbs.}}{16{,}000 \text{ lbs/in}^2} = 0.15 \text{ in}^2$$

Required moment of inertia:

$$I = \frac{P_{cr}.\ell^2.S}{n.\pi^2.E} \quad [4]$$

where n = 4; end condition; both ends fixed

S = 5; safety factor

$$I = \frac{2245 \text{ lbs} \times (8.5 \text{ ft} \times 12 \text{ in/ft})^2 \times 5}{4 \times (3.14)^2 \times 30{,}600{,}000 \text{ lbs/in}^2} = 0.095 \text{ in}^4$$

Chosen material:

1-1/2"ϕ standard steel pipe; $I_x = 0.310 \text{ in}^4$

$A = 0.801 \text{ in}^2$

Weight and cost

2.72 lbs/ft x 306 ft = 832 lbs.

832 lbs x $0.20/lb = $166.40

2. Load above the floor line

2.1 Load summary

Dead load of ceiling	800 lbs.
Dead load of interior walls	2,060 lbs.
Dead load of beams and studs	2,912 lbs.
Dead load of floor	5,370 lbs.

Live load on the floor [16]

Bedrooms: 30 lbs/ft^2 x 260 ft^2 = 7,800 lbs.

Other floors: 40 lbs/ft^2 x 700 ft^2 = 28,000 lbs.

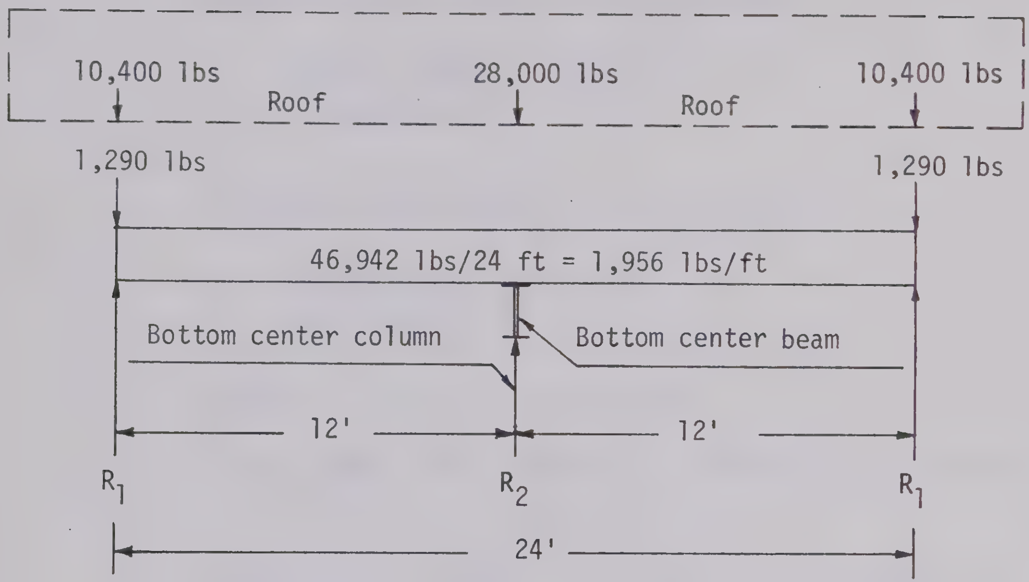
Sub total 35,800 lbs.

Total 46,942 lbs.

Total load of roof: 48,800 lbs.

Dead load of exterior walls on long line:

129 lbs/panel x 10 panels = 1,290 lbs/line



R_1 = 10,400 lbs + 1,290 lbs + (3/8) x 1,956 lbs/ft x 12 ft.

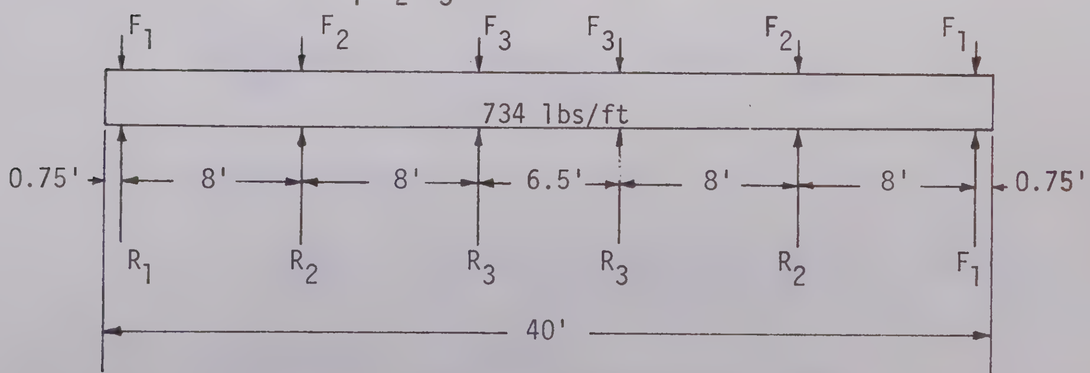
= 10,400 lbs + 1,290 lbs + 8,802 lbs = 20,492 lbs.

R_2 = 28,000 lbs + (5/8 + 5/8) x 1,956 lbs/ft x 12 ft.

= 28,000 lbs + 29,340 lbs = 57,340 lbs.

2.2 Bottom Center Beam and Bottom Center Column

$2(F_1+F_2+F_3)$ = 28,000 lbs



Maximum bending moment:

$$M_{max} = 0.125\ \omega\ell^2 = 0.125 \times 734\ \text{lbs/ft} \times (8\ \text{ft})^2$$

$$= 5{,}868\ \text{lb-ft} = 70{,}420\ \text{lb-in}$$

Required section modulus for steel beam:

$$S_x = \frac{70{,}420\ \text{lb-in}}{16{,}000\ \text{lbs/in}^2} = 4.40\ \text{in}^3$$

Required section modulus for Douglas Fir:

$$S_x = \frac{70{,}420\ \text{lb-in}}{1{,}500\ \text{lb/in}^2} = 47.0\ \text{in}^3$$

Sections of possible alternatives:

Steel beam; 6"x4"I, Light, $S_x = 5.07\ \text{in}^3$, $I_x = 14.8\ \text{in}^4$

8.5 lbs/ft

Douglas Fir: 4x2"x8", $S_x = 52.56\ \text{in}^3$, $I_x = 190.52\ \text{in}^4$

14.3 lbs/ft

Maximum deflections (Allowable deflection = 1/360):

6"x4"I, Steel;

$$\delta = \frac{5.W.\ell^3}{384.E.I_x} = \frac{5\text{x}734\ \text{lbs/ft} \times 8\ \text{ft} \times (96\ \text{in})^3}{384\text{x}30{,}600{,}000\ \text{lbs/in}^2\text{x}14.8\ \text{in}^4}$$

$$= 0.15\ \text{in}$$

$$\frac{\text{Deflection}}{\text{Span}} = \frac{0.15\ \text{in}}{8\ \text{ft} \times 12\ \text{in/ft}} = 0.0015 = \frac{1}{628}$$

4x2"x8" wood;

$$\delta = \frac{5.W.\ell^3}{384.E.I_x} = \frac{5\text{x}734\ \text{lbs/ft} \times 8\ \text{ft} \times (96\ \text{in})^3}{384\text{x}1{,}760{,}000\ \text{lbs/in}^2\text{x}190.52\ \text{in}^4} = 0.20\ \text{in.}$$

$$\frac{\text{Deflection}}{\text{Span}} = \frac{0.20\ \text{in}}{8\ \text{ft} \times 12\ \text{in/ft}} = 0.0020 = \frac{1}{480}$$

Weight and cost:

6"x4"I, steel; 8.5 lbs/ft x 40 ft = 340 lbs.

340 lbs x $0.20/lb = $68.00

4 x2"x8" wood; 14.3 lbs/ft x 40 ft = 571 lbs.

214 FBM x $0.36/FBM = $77.00

Maximum reaction is R_2;

$$R_2 = F_2 + \left(\frac{23+20}{38}\right) \omega \ell \ [4]$$

= 6,120 lbs + (43x734 lbs/ft x 8 ft)/38

= 6,120 lbs + 6,880 lbs = 13,000 lbs

Required area of section for steel;

$$A = \frac{R_2}{\text{Allowable stress}} = \frac{13{,}000 \text{ lbs}}{16{,}000 \text{ lbs/in}^2} = 0.82 \text{ in}^2$$

Required area of section for wood:

$$A = \frac{R_2}{\text{Allowable stress}} = \frac{13{,}000 \text{ lbs.}}{1{,}200 \text{ lbs/in}^2} = 10.833 \text{ in}^2$$

Required moment of inertia for steel;

$$I = \frac{P_{cr} . \ell^2 . S}{n . \pi^2 . E} \quad [4]$$

where n = 4; end condition; both ends fixed

S = 5; safety factor

$$I = \frac{13{,}000 \text{ lbs x } (7.5 \text{ ft x } 12 \text{ in/ft})^2 \text{ x } 5}{4 \text{ x } (3.14)^2 \text{ x } 30{,}600{,}000 \text{ lbs/in}^2} = 0.44 \text{ in}^4$$

Required moment of inertia for wood:

$$I = \frac{P_{cr}.\ell^2.S}{n.\pi^2.E} \quad (S = 10 \text{ is used for wood; [19]})$$

$$= \frac{13{,}000 \text{ lbs} \times (7.5 \text{ ft} \times (12\text{in/ft})^2 \times 10}{4 \times (3{,}14)^2 \times 1{,}760{,}000 \text{ lbs/in}^2} = 15.22 \text{ in}^4$$

Sections of possible alternatives:

2"ϕ standard steel pipe; I_x = 0.666 in^4

A = 1.08 in^2

6"x6" Douglas Fir*, I_x = 76.25 in^4

A = 36 in^2

Weight and Cost;

2"ϕ steel pipe; 3.65 lbs/ft x 45 ft = 164 lbs.

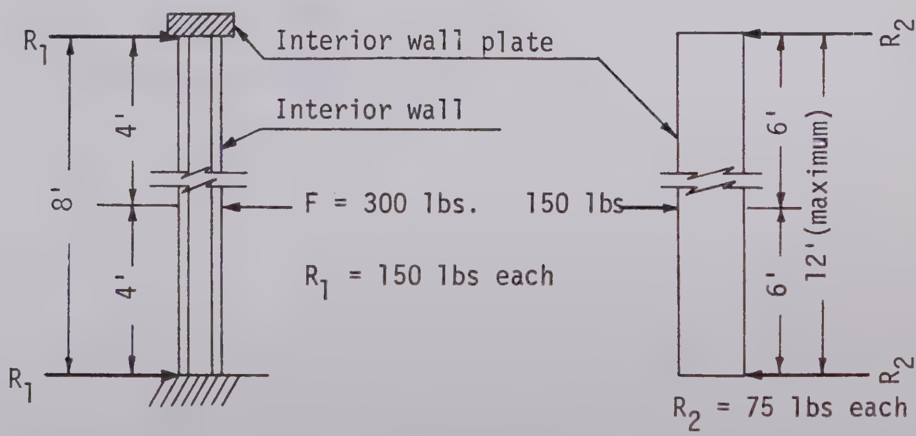
164 lbs x \$0.20/lb = \$33.00

6"x6" wood; 8.53 lbs/ft x 45 ft = 384 lbs.

144 FBM x \$0.36/FBM = \$52.00

3. Interior Wall Plate

Load Assumption



*The minimum size allowed for a wood column by the National Building Code.

Maximum bending moment;

$$M_{max} = (R_2 x 12\ ft)/4 = (75\ lbs\ x\ 12\ ft)/4 = 450\ lb\text{-}ft$$

$$= 5{,}400\ lb\text{-}in$$

Required section modulus for Douglas Fir wood:

$$S_x = \frac{M_{max}}{\text{Allowable stress}} = \frac{5{,}400\ lb\text{-}in}{1{,}500\ lb/in^2} = 3.60\ in^3$$

Chosen Section;

Douglas Fir; 2"x6", $S_x = 7.56\ in^3$, $I_x = 20.80\ in^4$

2.67 lbs/ft

Maximum deflection (Allowable deflection = 1/240):

$$\delta = \frac{W.\ell^3}{48.E.I_x} = \frac{150\ lbs\ x\ (12\ ft\ x\ 12\ in/ft)^3}{48x1{,}760{,}000\ lb/in^2 x20.80\ in^4}$$

$$= 0.255\ in.$$

$$\frac{\text{Deflection}}{\text{Span}} = \frac{0.255\ in.}{12\ ft.x12\ in/ft.} = 0.0018 = \frac{1}{534}$$

Weight and cost;

2.67 lbs/ft x 144 ft. = 384 lbs.

144 FBM x \$0.36/FBM = \$52.00